A KNOWLEDGE-BASED EXPERT SYSTEM APPROACH TO ANALYZE AND EVALUATE HIGHWAY CONSTRUCTION SCHEDULES

By

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To my Lord

"Who created me, and it is He who guides me;

"Who gives me food and drink;

"And when I am ill, it is He who cures me;

"Who will cause me to die, and then to live (again);

"And who, I hope, will forgive me my faults on the Day of Judgement;

"O my Lord! bestow wisdom on me, and join me with righteous;

"Grant me honorable mention on the tongue of truth among the latest (generations);

"Make me one of the inheritors of the Garden of Bliss;

"Forgive my father, for that he is among those astray;

"And let me not be in disgrace on the Day when (men) will be raised up;

"The Day whereon neither wealth and sons will avail;

"But only he (will prosper) that brings to Allah (God) a sound heart.

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Project scheduling is the practice of regulating and controlling the execution and performance of a construction project. The practice involves the establishing of a plan for the project execution based on engineering and administrative requirements, and available resources. Available computerized scheduling software had been criticized for its inflexibility, impartiality and inability to evaluate the schedule reliability.

In the field of highway construction in the state of Florida, the utilization of computerized scheduling techniques in preparing and monitoring construction projects has been observed to be very limited. In addition to software inflexibility, the absence of an activity-oriented coding system for highway construction projects is among the

reasons that pertain to the limited use of scheduling software. The vast anticipated growth in highway construction and maintenance projects, necessitate the utilization of a specialized domain-oriented computerized scheduling technique which will provide highway construction parties with schedule evaluation and activities execution regulations.

This study is focused toward the development of a knowledge-based diagnostic model that will examine the data produced by a computerized scheduling technique about an initial or in-progress highway construction schedule. The model evaluation will be done in compliance with facts and regulations pertaining to scheduling highway construction projects. The facts employed in this model include scheduling techniques knowledge, general construction scheduling knowledge and highway construction regulations.

The model knowledge base was developed using an expert system shell featuring the ability to interface dynamically with external data base files. Using an IF-THEN-ELSE production rules and a Standard Query Language program, the model prototype is designed to counsel the user with instructions and observed malfunctions regarding the schedule under evaluation. The results of the model prototype evaluation may be presented in a form of on-screen or printed reports.

CHAPTER 1
INTRODUCTION AND PROBLEM STATEMENT

Project Scheduling

Project scheduling involves the establishing of a plan for the project execution based on the engineering and the administrative requirements. It is also based on the available resources to assure a realistic and valid schedule for the completion of the project. In other words, project scheduling involves the identification of activities in a project, the determination of precedence relationships among them, the allocation of resources, and the estimation of duration for each of the activities.

Activity identification and determination of precedence relationships require experience-based decisions from the knowledge of construction processes, construction methods, and available technology. On the other hand, durations are estimated using average productivity rates for the planned quantity of work assigned to each activity (Moselhi and Nicholas, 1990).

Scheduling techniques for construction project management have been formally recognized and implemented since 1959. With the broad use of personal computers in the last decade, the use of computerized applications of project

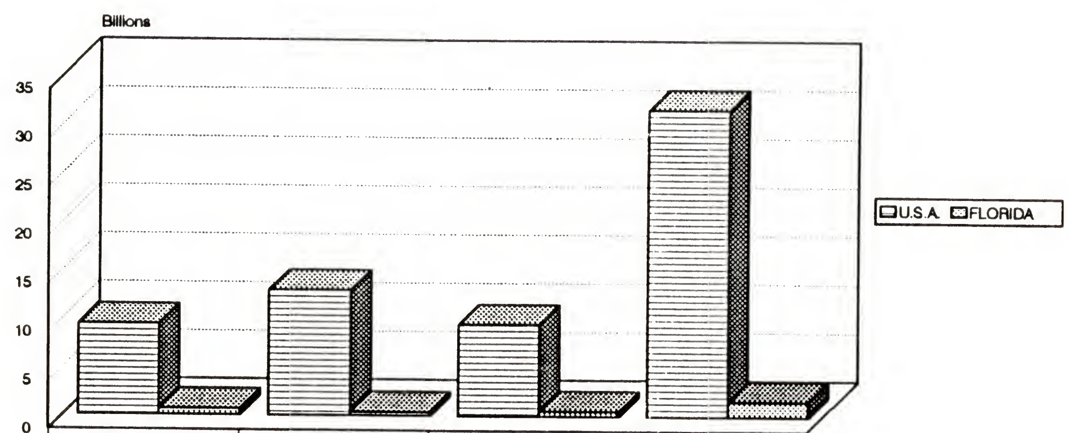
scheduling techniques has become more and more adequate. Although the implementation of these computerized techniques has become very popular in many construction fields, these techniques are still observed as incomplete project control tools.

Some noticed weaknesses of these computerized techniques are the following (De La Garza and Ibbs, 1990):

1. They cannot provide any qualitative or subjective project information, like the reasonability of activities' production rates.
2. They are very rigid and cannot be modified to incorporate various circumstances.
3. They are unable to provide meaningful diagnostic functions like the overall degree of schedule criticality.

Scheduling Practice in The Field of Highway Construction

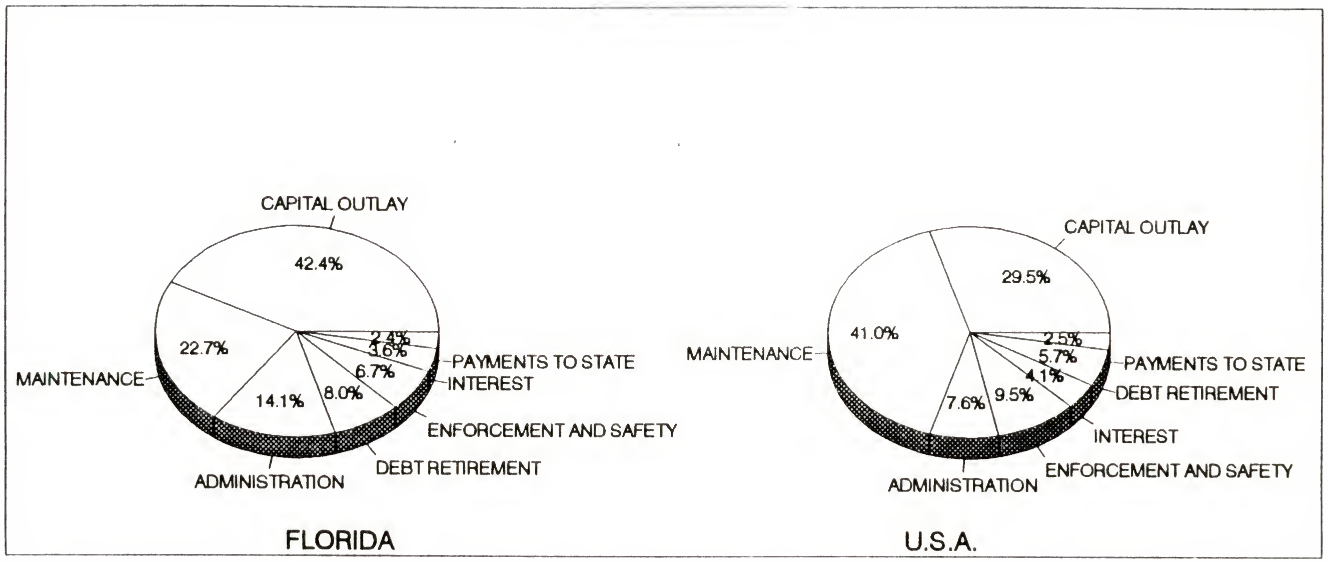
According to the Department of Transportation Federal Highway Administration, the total volume of disbursements of local governments for highway construction and maintenance projects in the year of 1991 surpassed 31 billion dollars. About 5% of this total disbursements is allocated to the state of Florida. Between 60%-70% of total disbursements by both the U.S. and the state of Florida were allocated to highway construction and maintenance projects. Figure 1-1 and Figure 1-2 display the disbursements in total and in



	CAP. OUTLAY	MAINTENANCE	OTHERS	TOTAL
U.S.A.	9.301	12.892	9.39	31.583
FLORIDA	0.65	0.348	0.534	1.531

SOURCE: Federal Highway Administration (1992).

Figure 1-1. U.S.A. and Florida state disbursements' volume for highways--1991.



<u>SOURCE</u>: Federal Highway Administration (1992).

Figure 1-2. U.S.A. and Florida state disbursements' percentages for highways--1991.

percentages for highway projects by all fifty states and by Florida in the year 1991. In Florida, the main client (owner) of these highway projects is the Florida Department of Transportation (FDOT). A small percentage of FDOT contracts is managed by project management consultant houses, while the rest are managed and supervised completely by field and resident engineers employed by the FDOT. Although these engineers possess a great deal of experience in supervising highway construction projects, most of them shy away from using computerized scheduling techniques in controlling and monitoring highway construction schedules.

During interviews, it has been observed that the acceptance of employing computerized construction project management techniques in highway construction projects, by both FDOT personnel and contractors, is very slow in coming. In fact until recently, FDOT Specifications did not require contractors to submit a comprehensive construction schedule. Presently, as a contract requirement, FDOT contractors have to submit construction schedules. However, neither FDOT personnel or contractors were utilizing these scheduling charts and data as effective management tools.

A key explanation of the slow acceptance of available computerized scheduling techniques in the highway construction is the difficulty construction parties were having in associating and interacting with these techniques. Uncustomized input/output notations, excessive details, and

inflexible report generations were noticed to be at the root of this difficulty. Another important reason for the slow acceptance of the available techniques is the absence of activity oriented coding system for the different activities involved in highway construction and maintenance projects. Instead of having a standard coding system for activities, the FDOT uses an elaborate coding system for pay items which are used to compensate contractors for their work.

These deficiencies in available computerized scheduling techniques and the incompatible coding system used by FDOT have resulted in limited utilization of valuable scheduling techniques. These in turn are denoted in poor management and control of highway projects. The poor management of construction schedules is considered to be a main factor for construction delays and disputes that causes the loss of millions of dollars of tax-payers' money.

Need for Improved Scheduling System

The development of a comprehensive and flexible computerized project scheduling technique that overcomes the present weaknesses of available scheduling techniques has been the target of many efforts in recent years. The advancement in the field of Artificial Intelligence (AI) has triggered many attempts to apply knowledge-based expert systems (KBES) in developing a system that generates or evaluates construction schedules. Because of the diverse knowledge of the different types of construction works, the

applications of KBES had to be specialized and limited. Most of these attempts or efforts gave some insight as how to approach the issue in the field of building construction, but none tackled the issue of developing a KBES that will enhance and customize available scheduling techniques to the need of highway construction management practices.

The enormous amount of money involved in highway construction and maintenance and the expected increase in its volume in the future amplify the need for a customized and enhanced scheduling technique. A KBES approach that will satisfy this need and utilize expertise of highway construction is an appropriate answer. The KBES would be able to serve all highway construction parties including FDOT personnel, consultants and contractors.

Research Objectives

The development of a KBES that enhances and customizes computerized scheduling techniques for highway construction projects requires satisfying five objectives.

The first objective of this research is to develop a knowledge base that accommodates expertise in highway construction scheduling according to FDOT specifications. This knowledge base should include FDOT contracts' regulations and specifications in addition to the general construction practice regulations and the practiced scheduling techniques. The acquisition of this knowledge will be done by reviewing construction scheduling textbooks

and articles, FDOT's technical manuals, and reports. Knowledge acquisition will also be done by interviewing experts in highway construction including FDOT scheduling engineers, project engineers, highway construction consultants, and highway construction contractors. The knowledge base developed by during the acquisition stage should contain facts and experiences pertaining to the analysis and evaluation of preparing and monitoring construction schedules.

The second objective of the research is to propose a sample coding system for highway construction activities that parallels the pay-items' coding system. The proposed coding system in conjunction with FDOT average estimated production rates and the appropriate unit measure for each activity will be used to assist in evaluating and analyzing the project schedule.

The third objective of this research is to develop the Highway Construction Scheduling Analysis System (HWCSAS) that can imitate the reasoning process of an experienced scheduling engineer, in highway construction. The reasoning process will be done by judging the accuracy and soundness of an initial or in-progress project schedule. The proposed HWCSAS should enhance available scheduling software by furnishing essential attributes in highway construction scheduling. These attributes include judging the validity of the project schedule, detecting its complications with

some degree of reliability and proposing potential reasons for scheduling problems.

The fourth objective of this study is to implement the proposed HWCSAS by developing a system prototype. Two factors should be considered when developing the HWCSAS prototype. The first factor is to minimize cost making use of available expert system shells and commercial scheduling software. The second factor is to enable the system to be executed in personal computers to permit its use both in the office and on the construction site.

Therefore, the system implementation will be done by using a commercial expert system shell (EXSYS Professional) which will interface with a commercially available scheduling software (SURETRAK Project Scheduler) to interpret and analyze construction schedules. The reasons for choosing both software include simplicity, affordability, broad-use and the ability to interact and exchange data with other software. The HWCSAS will be designed to have the following functions:

1. Import scheduling data produced by SURETRAK project Scheduler about a specific highway projects.
2. Analyze the proposed project schedule based on highway construction scheduling facts and experiences.

3. Report back the findings and suggest improvements to the user.

Figure 1-3 display the communication mechanism between the expert system shell and the scheduling software.

The final objective is to test the system prototype after its construction. The validation process will be done by testing two initial highway construction schedules. To enable the proposed HWCSAS to evaluate and analyze in-progress schedules, additional controlling and testing rules will be added to the system. Due to <u>EXSYS Professional's</u> limitations at this stage, the analysis of in-progress schedules will not be furnished in the system prototype.

Examples of the questions that the HWCSAS should diagnose to validate the initial schedules are

1. Does the schedule meet the contract requirements?
2. Is the network's critical path reasonable?
3. What is the overall degree of schedule criticality?

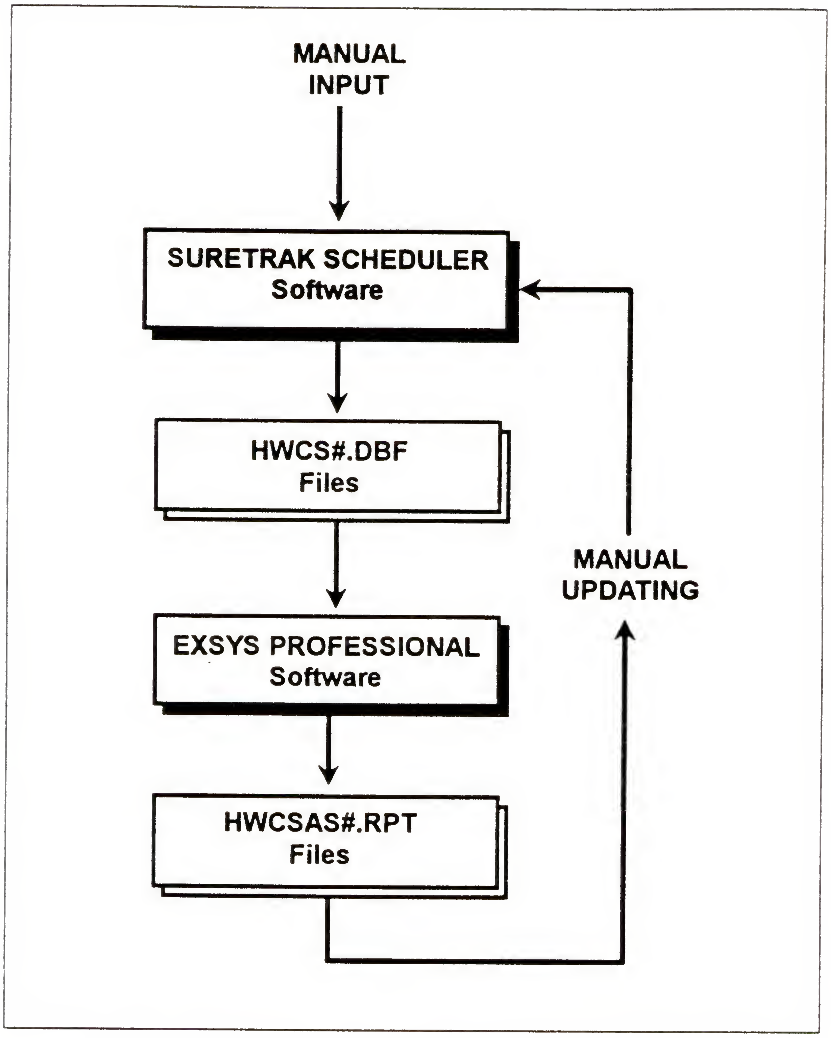


Figure 1-3. Highway construction scheduling analysis system communication mechanism.

CHAPTER 2
REVIEW OF LITERATURE

Introduction

Existing scheduling techniques have been criticized widely for rigidity and incompleteness in recent years. In the field of highway construction, the reluctance to employ scheduling techniques in controlling and monitoring construction schedules is even more apparent due to other reasons explained in Chapter 1. To fulfill the first objective of this research, the literature review carried out during this research explored many domains. These domains included:

1. Construction scheduling fundamentals and the professional practices of planning and monitoring construction schedules.
2. FDOT specifications and regulations for scheduling highway construction and maintenance projects.
3. Expert systems technology and the different types of knowledge representation.
4. The different attempts to apply expert system technology in the field of construction scheduling.

To explore these domain sources, a computer database search through Southern Technology Application Center (STAC) in Alachua, Florida, was conducted in March, 1991. An update search was conducted again in January 1992. The search located 126 published articles, of which over 61 were related to the scheduling practice and the application of KBES.

For the rest of this chapter and Chapter 3, an overview of construction scheduling fundamentals and FDOT scheduling regulations for highway construction and maintenance projects will be addressed. In Chapter 4, expert system technology will be reviewed and discussed. The discussion will also include existing efforts and literature dealing with applying expert systems in construction scheduling. In Chapter 5, the expertise collected during the knowledge acquisition process will be organized and presented as a knowledge base for the proposed HWCSAS.

Construction Schedule's Purposes and Objectives

A schedule is a time-phased plan for accomplishing the tasks that make up a project. It is based on specified logical relationships between the tasks and estimated task durations. There are many purposes and objectives for construction project scheduling, that will help ensure the common goal of all project participants and avoid misunderstandings during the execution of the work. These

purposes and objectives are summarized in the following statements (Hartley, 1989):

1. The project schedule is a management tool, which is used as a basis for decision making. As such, the schedule is used by the project management team to plan, schedule, monitor, control, report, and forecast.
2. The project schedule is used by all project participants. It should be influenced by activities of owners, contractors, vendors, subcontractors, utility companies, and government entities alike, but in varying degrees.
3. The project schedule is a dynamic document, reflecting both the project's original plan and the subsequent events, which influence the original plans as the project proceeds.
4. The project schedule incorporates all direct project activities, at varying levels of detail, and interrelates those activities and necessary resources to predetermined milestones.
5. The project schedule establishes the relative priorities for all activities critical to achieving the earliest project completion date.
6. To achieve maximum benefits, project participants must be directly involved in the

schedule preparation and fully committed to the objectives of the approved project schedule.

Scheduling Techniques Types

The assurance that the contractor will execute the project on time requires the use of a valid scheduling technique. There are three basic types of recognized scheduling techniques; time scheduling techniques, network scheduling techniques and probabilistic network scheduling techniques.

Time scheduling techniques includes the bar chart (Gantt chart) technique and the line of balance technique. Network scheduling or critical path method (CPM) techniques includes arrow diagramming technique and precedence diagramming technique. Probabilistic network scheduling techniques include program evaluation and review technique (PERT) and the Monte Carlo simulation technique.

Network scheduling or CPM technique had become the leading scheduling technique in the last decade because of its clarity, flexibility and comprehensiveness. Historically, the initial type of CPM technique (arrow diagramming method) was developed in 1957 by the DuPont Company. In 1964, a modified type of CPM technique (precedence diagramming method) was developed by IBM computer application group (Beach, 1992). Since then, an advanced computerized precedence diagramming method had been recognized to be the most suited for construction management

activities such as planning, scheduling and monitoring. Furthermore, the use of this advanced technique provided additional features such as documentation needed for contracts' negotiation, changes and claims.

Critical Path Method

The CPM is an activity oriented method, where tasks are built and resources are assigned by activities. The logic network allows the complete planning of a project independently and with little concern about scheduling. In the CPM, each activity is represented by a rectangular figure and the dependencies between activities are indicated by sequence lines going from one activity to another. The identity of the activity and a considerable amount of other information pertaining to it are entered into its rectangular box. The advanced CPM has the ability to represent different lags or complex relationships between activities such as finish to start, start to start, finish to finish and start to finish relationships.

In the CPM technique, scheduling involves several basic arithmetic computations once the project plan is complete. The first of these computations deals with the resources available to perform each activity and the resulting duration of that activity. The second group of computations involves two type of arithmetic passes, the forward pass and the backward pass. The forward pass is the procedure by which the early times for a project are

calculated. It is called the forward pass because it proceeds "forward" along the logic diagram from left to right. The backward pass is the procedure in which the late times of a project are determined. It is called the backward pass because it proceeds "backward" along the logic diagram from right to left. The forward pass and the backward pass computations would result into four sets of figures for each activity. These figures are early start, early finish, late start and late finish. Figures 2-1, 2-2 and 2-3 are examples of forward pass calculations, backward calculations, and a simple schedule network with the ideal information pertaining to each activity, respectively.

These computations when calendar dated, provide a calendar schedule for the job in its entirety and for each activity within the project. This very intense job analysis provides field construction and project management with plenty of information concerning expected job performance. By calculating the time boundaries for each activity, we determine how much flexibility is possible in these start and finished times, given the constraints that have been identified as affecting the project. We also determine the activities that are significant to the success of on-time performance, i.e., the critical path activities (Muller, 1986).

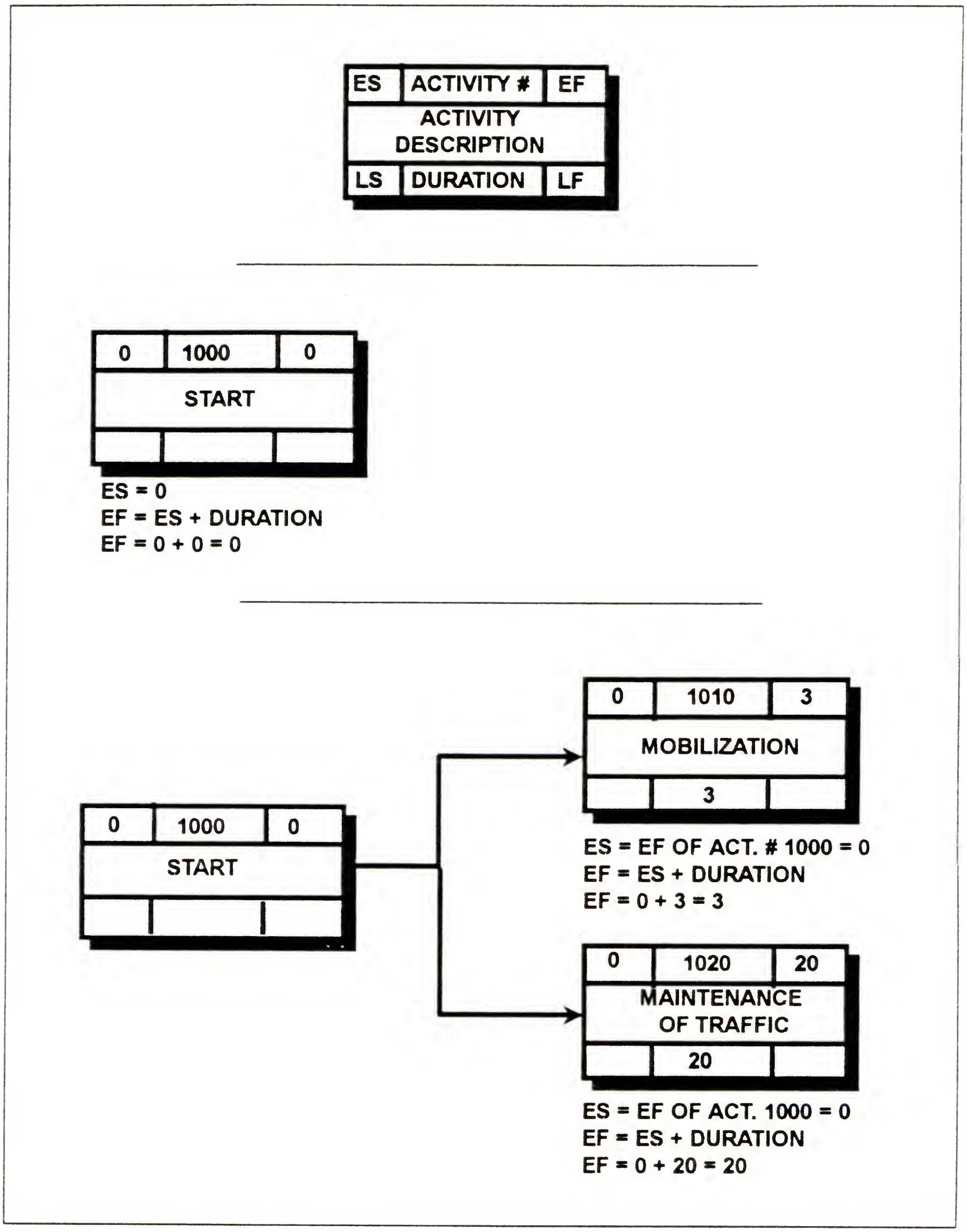


Figure 2-1. Examples of schedule forward-pass calculations.

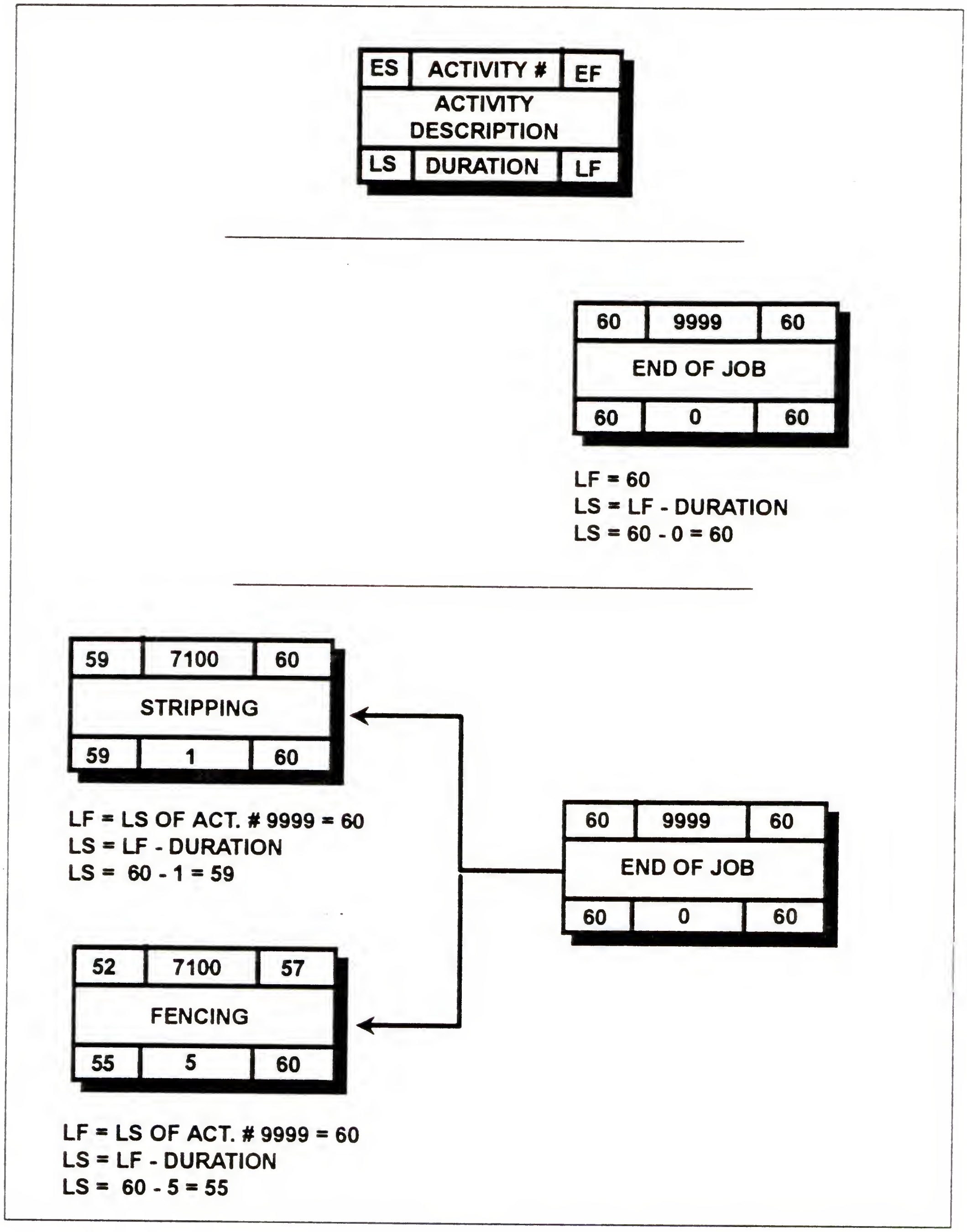


Figure 2-2. Examples of schedule backward-pass calculations.

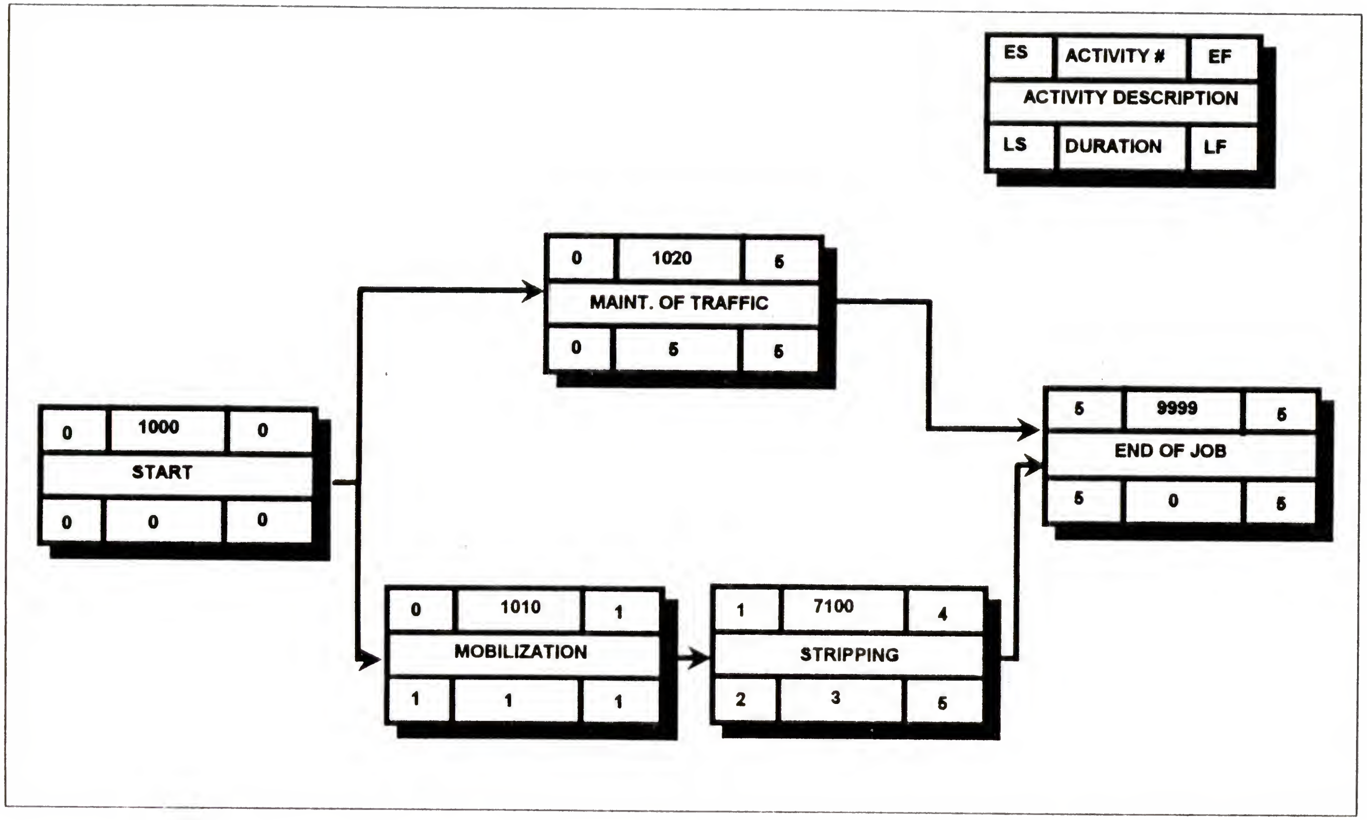


Figure 2-3. Simple highway construction schedule diagram.

Planning the Project's Schedule

Planning is the division of a workable scheme of operations to accomplish an established objective when put into action. Of the most time-consuming and difficult aspects of the job-management system, planning is considered the most important. It requires an intimate knowledge of construction methods combined with the ability to visualize independent work elements and to establish their mutual interdependencies. Construction schedule planning must be performed by people who are experienced in and thoroughly familiar with the type of field work involved (Clough and Sears, 1979).

There are several basic parameters that govern the preparation of all project schedules. These parameters are as follows (Hartley, 1989):

1. The project's participant involvement is critical in preparing any schedule. Schedules should not be developed in a vacuum without the benefit of participant knowledge. In many respects the scheduling engineer functions as a coordinator who assembles and integrates the thoughts and plans of all project participants.
2. Activities should be identified to describe the project in sufficient detail to satisfy the schedule objectives.

3. Durations should be assigned to each activity based on documented previous experience of the organization and other project participants. Durations should also be based on historical performance or quoted data from outside vendors or subcontractors.
4. Interrelationships of the identified project activities should be analyzed to reflect the restraints between and among them.
5. Responsibility centers should be identified for the execution of each activity. These centers may be either individuals or organizational entities.
6. Resource assignments should be made to either individual activities or groups of similar activities.

Construction Activity's Properties

An activity is an item of work with a clearly defined beginning and end. Each of the construction activities should show a beginning and ending work date, a duration, and a monetary value. Sequencing and interdependencies between the construction activities must be logical and according to the work order to be accomplished as planned by the contractor (Pierce, 1988).

Each activity of the initial schedule has both early and late dates. Early start is the earliest possible time

an activity can start assuming all previous activities have been completed. Early finish is the earliest possible time an activity can be completed, assuming that all previous work has been completed. In practice, the early finish is equal to the activity time added to the early start time. Late finish is the latest time an activity can finish, and still not delay the completion of the project as a whole. Late start is the latest time an activity can begin, and still not delay the final completion. The late start is equal to the activity time subtracted from the late finish.

It is best to set the planned schedule based on early rather than late dates. This approach supports an "earliest possible" perspective, and it does not allow putting off an activity until the last possible start date. The idea is to promote an attitude, which encourages getting on and off the job with each item of work as rapidly as possible.

It is important to note that there are sometimes legitimate reasons for changing the planned schedule dates. For example, activities could be delayed to use labor or equipment more efficiently. The planned schedule should be changed to reflect this kind of modification and the change and the reasons behind it should be clearly explained to project personnel. Another important note is that some activities will be critical, while others will have float and can therefore be started at various times. It is important not to manipulate float when planning the

construction schedule. This practice defeats the logic of urgency created by using early start dates in the target schedule.

Construction Activity's Categories

In construction scheduling there are many categories of activities such as task, procurement and submittal activities. Beside task or work activities, a construction schedule should include separate procurement time (for materials and equipment) and review time (of shop drawings) where they are appropriate and essential to the time completion of the project. For example, if there is a submittal log, it should be considered as an activity and should be tied to the schedule.

Task or work activities are activities done by the contractor to complete the contracted job. Task activity's duration ranges usually from 1 to 30 calendar days. To insure proper control, a typical task activity duration should range between 5 and 25 calendar days. As a rule of thumb in the construction industry, durations of activities in the first third period of a project should not exceed 5% of the project's total span, durations of activities in the middle third should not exceed 10%, and durations of activities in the last third should not exceed 15%. These values are guidelines, not hard rules (De La Garza, 1990).

Task activities with long durations are difficult to measure. They usually indicate the aggregation of many

subactivities into a more general one. An activity with long duration that cannot be adequately measured and monitored should be rejected or divided into more detailed activities. On the other hand, a task activity with long duration, low value, and low float may be regarded as unimportant and thus allowed to keep its duration. The practice of splitting activities into misleading categories, e.g., 30% complete, 60% complete, and 100% complete should be avoided except for design activities (Appendix A: 2.a.). This practice gives the impression of trying to manipulate float by extending activity duration. This in turn makes the $/day index drop to a level, which suggests front-end loading of earlier activities.

The second type of construction activities are procurement activities. Procurement lead time must be an integral part of the construction schedule and must be represented as a procurement activity. These activities are assigned for durations needed to acquire materials or equipment. The "procurement chain" of activities for major milestones consists of award, submit, review, approve, procure, deliver, and install. A dollar value must not be placed on these activities. Long term procurement activities with durations of more than 30 calendar days should be accepted (Appendix A: 2.c.).

The third type of activities are submittal activities. These activities represent the contractor's preparation and

submittal of shop drawings, catalog cuts, samples, etc., and the owner review and approval actions. All materials and/or method requiring prior approval must have their submittal activities represented in the network. If any part of the design is not finalized, then that part should be a separate activity. Therefore, the owner controlled activities that affect construction progress should be included in the network. Reasonable durations should be assigned to submittal activities by the contractor and approved by the owner. The monetary value of submittal activities should be zero. The cost of preparing submittal is considered part of the overhead and the contractor must distribute costs to other activities. For submittal activities like design approval, some highway construction experts accept the practice of assigning monetary values for these activities (Appendix A: 1.f.).

Guidelines for Estimating Activities' Durations

An activity duration is the calculated or estimated time for an individual activity to be completed. To secure a sound construction schedule, the estimation of each activity duration must be well predicted. Listed below is some guidelines to aid in estimating activities' durations (Pierce, 1988):

1. Assume each activity will be done normally; initially plan all activities in terms of ideal

time, and then change only those that must be changed for valid reasons, such as overall time.

2. Evaluate each activity independently; the scheduler should compute individual activity times as if no other work existed, and then account for constraints as necessary and as they become known in the scheduling process.
3. Activity duration limits usually range from 1 to 30 calendar days. Reasonable activity durations range from 5 to 25 calendar days.
4. Durations should be based on the time of the year the operations are to be executed.
5. The initial activity duration is based on known standard productivity for a type of crew. This duration is independent of the season of the year the activity to be scheduled.
6. Use consistent time units.

To verify if the durations assigned for each activity are reasonable or not, these durations should be compared to a product of the quantities estimated for each activity and the production rate for each activity. This will require the knowledge of the production rates of the schedule's activities. Table 5-3 shows some of the estimated production rates developed by the FDOT for major highway construction activities involved in the construction schedule.

Procedure for Establishing Contract Duration

Contract duration is the time, measured in calendar days, allowed for the completion of a contract. In highway construction, the FDOT developed a procedure to establish a contract duration. FDOT's calculation of contract duration does not include additional time for severe weather conditions. The procedure for calculating contract duration used by the FDOT is the following (FDOT Procedures, 1992):

1. Review the project plans and specifications with special emphasis on maintenance of traffic. If the project has more than one phase, determine what work can be done in each phase.
2. List the required activities for each phase on the form for contract durations. The list does not need to be extensive. However it needs to include all controlling items of work or activities on the critical path.
3. List each quantity of the unit of work that will be used as a basis of for estimating that activity's duration. On a project with more than one phase, use only that quantity associated with that phase.
4. Use the production rates and charts to convert the units work into work days. Repeat the process for each activity and for each phase.

5. Multiply each of the work days by a factor of 1.46 to convert them to contract days (for 5 working days per week contracts). The factor of 1.46 is based on 250 working days per year. When using a computerized scheduling software package, work days can be converted to calendar days using the program's calendar function.
6. After computing the contract time, 15-25 days general time is normally added. Do not multiply the 15 days by a factor. The contract time is now established.

Activities' Codes, Descriptions and Unit Measures

Each activity must be coded and must have a standard description of the work involved. Codes must be complete, correct, and must reflect the nature of the work. Codes and descriptions should follow the work breakdown arrangement specified in the contract, if any. Each description should be unique, and nonstandard abbreviations should be avoided so any one familiar with the construction work can understand it (De La Garza et al., 1990).

The FDOT has established a coding system that deals with pay items list, but no effort was done in developing an activity oriented code system (Appendix A:1.d. and 6.a.). To overcome this incompatibility and to establish the database that will be used as a base for analyzing and evaluating the construction schedule where each activity

within the schedule must have a designated code that will be referred to during the analysis process, the researcher suggested a coding system comparable to the pay item system. Each activity is assigned a number that matches the numbers assigned to the pay-items of that activity. Example of the suggested coding system is the "drainage" activity. Drainage is assigned the number 4250, which matches the numbers of the following pay-items:

425-1-aab	Inlet
425-2-aab	Manholes
425-3-aab	Junction Boxes
425-78	Precast Cap for Inlet

A sample list of major activities' descriptions in highway construction and maintenance and their suggested codes and unit measures are presented in Table 5-1.

<u>Construction Activity's Constraints</u>

Construction activities' constraints define the logical relationship between activities and events. Four types of constraints are used to define the different relationships between activities (Busch, 1991):

1. <u>Finish to Start</u>: This is the most frequently used type of constraint. It indicates that the succeeding activity cannot start until the preceding activity is totally complete. Lags on finish-to-start constraints usually suggest date rigging. All lag values must represent time

consumed by effort for valid time reserve calculations. To be valid, a lag on a finish-to-start constraint could be replaced with an activity that represents definable project effort.

2. Start-to-Start: A constraint that indicates the succeeding activity can start after a specific time from the preceding activity start. Start-to-start constraints should have lag values representing a portion of the predecessor activity. The absence of a lag value on a start-to-start constraint normally indicates improper modeling of activity overlap. The value of the lag on a start-to-start constraint should be less than the predecessor activity's duration.

3. Finish-to-Finish: A constraint that stipulates the succeeding activity can only be completed after a specified time from the completion of the precedent activity. Finish-to-finish constraints should have lag values representing a portion of the successor activity. The absence of a lag value in a finish-to-finish constraint normally indicates improper modeling of activity overlap. The value of the lag on

finish-to-finish constraint should also be less than the successor activity's duration.

4. Start-to-Finish: A constraint that is rarely used and indicates that the succeeding activity cannot finish until the preceding activity has started. Start-to-finish constraints or negative lag values are impractical and should be discouraged.

Figure 2-4 shows the graphical representation of the four constraints explained above.

The Critical Path

The critical path is the set of activities where the early times of which are equal to their late times and the total float equals 0. In other words, the critical path represents the group of activities that must start on time to keep the project as a whole on time. They are recommended to have a duration less than one pay period or that they can be easily measured in terms of percentage complete. In the construction industry, this is especially true in the case of finish work, which is typical cause of delays.

The critical path usually consists of relatively few activities of the baseline schedule. Construction schedules always have a critical path and a series of three or four

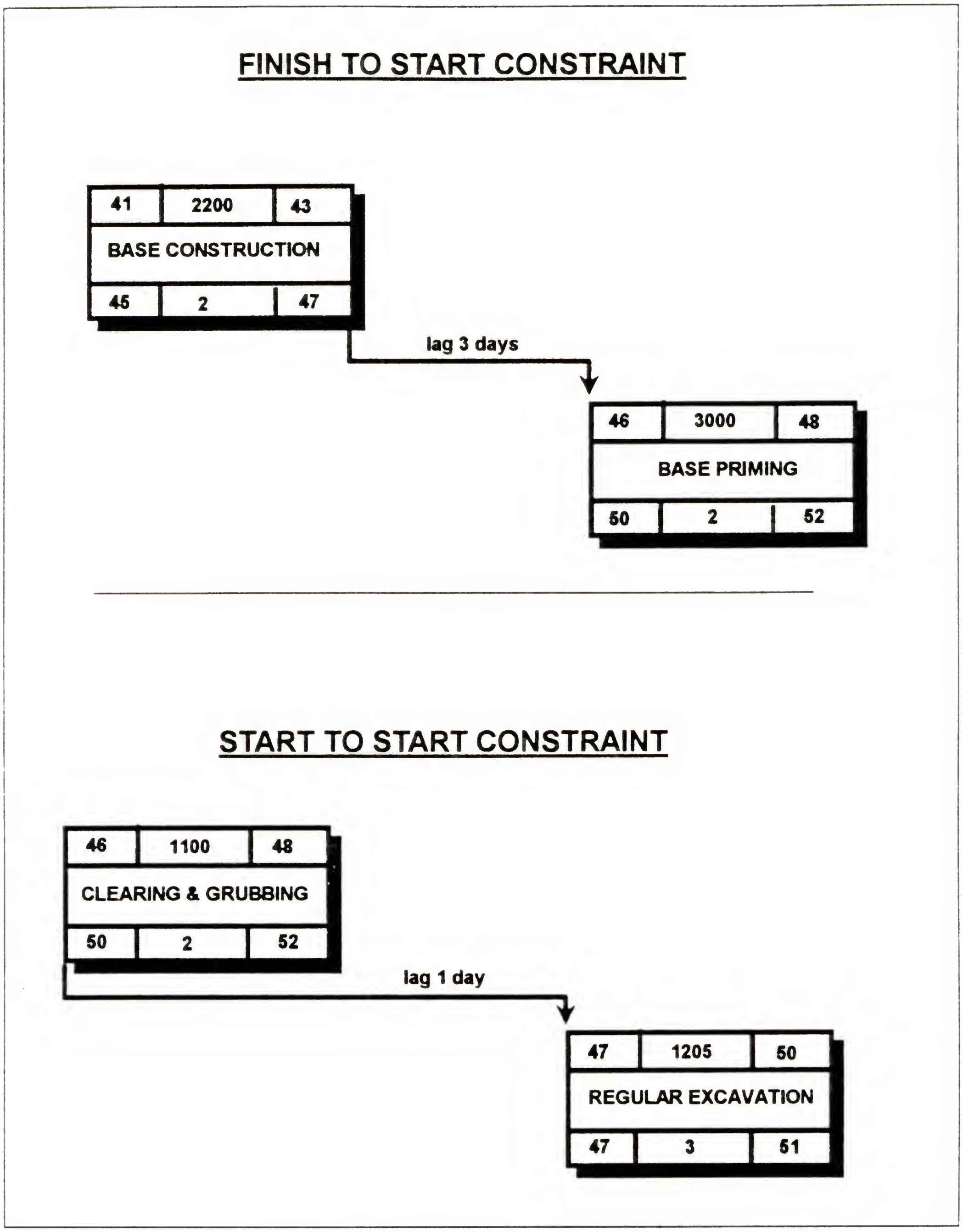


Figure 2-4. Types of construction activities' constraints.

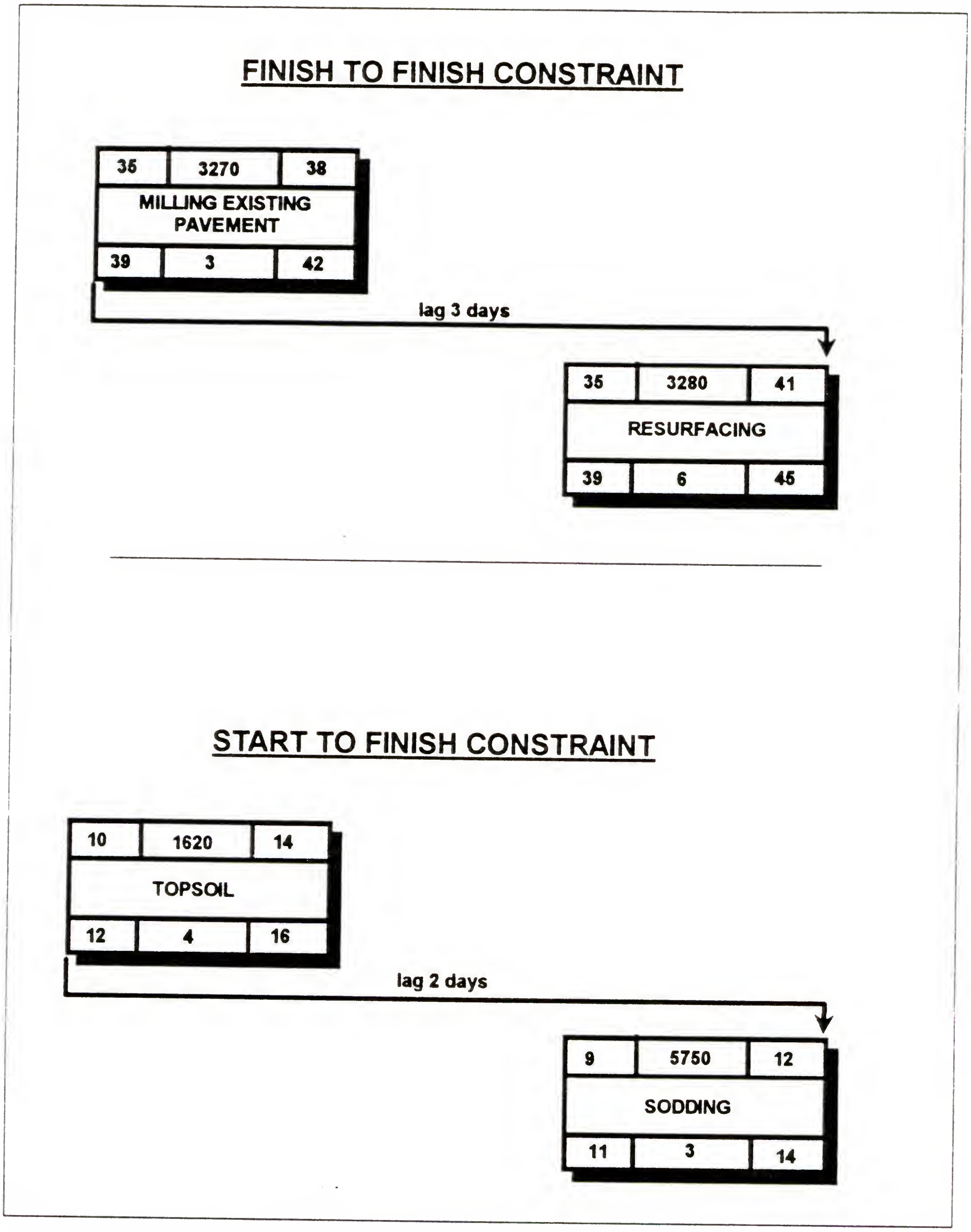


Figure 2-4.--Continued.

"low float" paths. In general construction, if the critical path activities rises much above 20% of the project's total activities, this means that the contractor failed to schedule the project adequately. Therefore the project becomes difficult to manage, and it should be rescheduled. This rule of thumb may not be applicable for highway construction, because most highway projects tend to be linear in execution (Appendix A:1.j.).

Critical activities should have enough detail in analyzing the ratio of (critical/total) activities. A small index would indicate too little detail in the critical path and too much detail in noncritical activities. If many parallel paths and/or a large number of critical activities exist, it is likely that some durations have been overstated for the purpose of eliminating float. Managing simultaneous critical paths is harder than managing a single one. If there is slippage in the schedule, logic changes will show most likely work done concurrently (De La Garza et al., 1990).

Overall Completion Date

Contract specifications define the period within which work must be completed from notice to proceed. The overall completion date of the planned schedule must comply with the contract completion requirements. A schedule consuming more than the specified number of contract days is not acceptable (De La Garza, 1990). Although a schedule showing early

completion is acceptable in general construction, provided acceptable time constraints are placed on administrative activities such as submittal activities. In highway construction, the FDOT do not approve such schedules, without changing the contract documents, to avoid future obligations (Appendix A:1.1., 3.d. and 6.c.).

Subcontractor Participation in Schedule Preparation

Subcontractor plans should be an integral part of the construction schedule. Any subcontractor performing 10% or more of the total contract work is considered a major subcontractor, and should participate in the contractor's development plan. Major subcontractors may not have been identified at the time the contractor submitted his schedule, but those who have should be involved in its preparation. Individuals of a particular trade should be able to see a "detailed" description of their tasks with interfaces to the general plan. The work for each subcontractor should be identified with a special coding scheme, so that the percentage of work by subcontractors is calculated (De La Garza et al., 1990).

Activity's Cost

The monetary value of each activity should conform to the range specified in the contract. In addition, the monetary value assigned to each activity should represent a reasonable amount for that work. This analysis may be based

on the cost of similar work completed recently. The FDOT has produced a state-wide historical average unit price for the different pay-items that may be involved in highway construction projects. Using the proper unit measure for construction activities, an average unit price for most task activities was configured by the researcher. A sample list of these unit prices and their proper unit measures is shown in Table 5.3. A typical accumulative cash flow curve would show one-quarter of the cost committed at the end of the first third of the project, and three-quarters of the cost at the end of the second third. In highway construction, some projects' cash flow curves may not follow this general assumption depending on the project type, season and location (Appendix A: 1.o.). Costs associated with an activity play no role in constraining its duration (De La Garza et al., 1990).

Weather Sensitive Activities

An activity is considered weather sensitive if it is affected by either moisture, temperature, or wind. Weather-related time extensions are difficult to get, unless very abnormal weather conditions are present. It should be determined if weather prevented the contractor from doing weather sensitive work, or lack of weather protection damaged work already in place. The FDOT does not include allowance for anticipated delays due to weather in establishing contract time. Instead, the FDOT guarantees

weather days to the contractor once it occurs (Appendix A: 2.b.). In typical construction contracts the conditions that grant weather-related time extensions are the following (De La Garza et al., 1990):

1. The contractor being unable to work at least 50% of the normal work day on predetermined controlling work items.
2. The contractor must make major repairs to the work damaged by weather, providing the damage was not attributable to a failure to perform or neglect by the contractor.

Milestones

Milestones are specific and obvious points of achievement marking the start or completion of stages of a project. These can be major milestones identifying major phases of a project and intermediate milestones for minor points. The estimated completion time of each milestone is determined from the initial version of the plan (Harrison, 1981).

The list of activities should include milestones when required by the plans or special provisions. In a project with more than one phase, each phase and its completion date will be adequately identified and no activity will span more than one phase. Intermediate milestones should be determined and incorporated in the schedule according to contract specifications. Intermediate milestones are very

effective to determine if the critical path is reasonable. In preparatory milestone schedules, it is common to avoid showing float because the idea is to block off time to get the overall completion date (De La Garza et al., 1990).

Activity's Float

Many projects get behind schedule because of slippage of activities on the critical path, but many also become late because of slippage of noncritical activities. It is essential that the float, that is, spare time on noncritical activities to be monitored from one update of the network to another, to check for slippage. There are two types of float: total float and free float. Total float is the difference between the early and late times on an activity; it is the allowable delay in starting the activity. Free float is the spare time available to an activity when all activities in the have are started as early as possible. It is the difference between the earliest finish date of an activity and the earliest start date of the immediately following activity (Harrison, 1981).

Schedules having an excessive number of critical activities should be questioned and reviewed. Zero floating a schedule's network defeats its fundamental purpose. One must know which activities are critical and which are not to effectively manage the work. Float may be used as necessary by the contractor without a change in the contract price. In general construction, when the owner wishes to use float

to absorb change order work, he/she must negotiate a fair price for the amount used. This solution lies in a policy that says float has value to the contractor and must be treated as any other resource when pricing a change order. The compensation for using float to accommodate changes to the project should include both the direct effects of such a change and the indirect impact such as manpower utilization. In highway construction, using float to absorb a change order does not entitle the contractor to any compensation (Appendix A: 1.e., 5.c. and 6.b.).

Float has more value early in the life of the job than when the job approaches completion. The reason is that, as the job progresses, the remaining risk factors diminish. For a given activity, float increases in value inversely to its quantity because uncontrollable events causing small periods of delay are more likely to happen than those producing longer delays. In general construction, activities with very high float are not recommended. Although the activity's logic may be correct, this implies that the activity has not been integrated to optimize manpower and other resources (De La Garza et al., 1990). This may not be applicable in highway construction practice because some of the activities involved are independent by their nature from the schedule main flow (Appendix A: 1.k.).

Front-End Loading Practice

Front-end loading is the practice of placing an excessively high monetary value on activities scheduled for completion early in the project. Front-end loading practices are discouraged in the main construction industry and considered illegal. In highway construction, front-end loading practice is accepted, while back-end loading practice is discouraged in order to detect delinquency (Appendix A: 1.m., 3.e., 5.b. and 6.d.). Labor intensive activities should be likely candidates for front-end loading because there is no retainage on each payment request (some FDOT projects might apply retainage to labor intensive activities, see Appendix A: 1.n., 3.f. and 6.e.). On the other hand, labor-intensive activities are very quantitative, and thus, it is easy to detect if they are front-end loaded. Money spent on electrical and mechanical activities is not only a function of performance and productivity, but also of delivery of initial equipment. This may give the false impression of front-end loading. For example, an operation such as "installation and hookup of auxiliary power unit" can be legally front-end loaded if the procurement of the motor control center is not represented by a single activity. If so, it would be wrong to prorate the cost of such an item or to say the owner does not pay for it until it is hooked up.

The process of determining if there is evidence of cash flow front-end loading is the following (De La Garza and Ibbs, 1990):

1. Assess if the mobilization costs are accurate, given the contractor's equipment list.
2. Are there items that are likely to overrun quantities? If so, does their cost appear reasonable in relation to similar items with larger quantities?
3. Are unit prices of early activities greater than unit prices of similar activities scheduled toward the end of the project?
4. Is the percentage of cost committed at one-third and two-thirds of the project greater than one-quarter and three-quarters, respectively? Note: This measure should be applied with caution because the existence of this fact also indicates that the contractor is taking too long to finish out. It also indicates that the preceding two-thirds of the project were scheduled too early, thus making the schedule too optimistic.
5. Perform a variance analysis on the $/day index to determine the activities that fall outside an acceptable range, i.e., (1 standard deviation - mean + 1 standard deviation). Such activities

may be then correlated with their planned time, i.e., one quarter versus four quarters.

Comparison of Highway Construction Schedules with Building Construction Schedules

Scheduling highway construction projects differs considerably from building construction projects. Highway construction schedules usually involve a relatively small number of basic work activities, and each activity will have a little change from one project to another project. On the other hand, building construction schedules involve a large number of distinct work activities. Highway construction projects are considered as linear process projects. They proceed along the roadway from beginning to end. In contrast, building construction is a complex sequence of interdependent activities (Ellis, 1989).

Florida Department of Transportation Schedule's Review Guidelines

The FDOT has generated a set of guidelines to review contractor's work schedules to assure its reasonability. These guidelines are the following (FDOT Standard Specifications, 1991):

1. Confirm that it represents a reasonable plan for accomplishing the work. The contractor shall commence work according to his approved working schedule. He shall provide sufficient labor, materials and equipment to insure the completion

of the work within the time limit set forth in the proposal.

2. Ensure the work is broken down and identified well enough to permit acceptable monitoring and reporting progress.
3. Ensure that monetary values are correct for payment purposes.
4. Ensure that the quality control program is submitted and covers the quality control sampling and testing proposed to be carried out.
5. Within 21 calendar days after the contract has been awarded or at the pre-construction conference, whichever is earlier, the contractor shall submit a work progress schedule for the project. The schedule shall show the various activities of work in sufficient detail to demonstrate that the contractor has a reasonable plan to complete the project on time.
6. Sufficient association shall be conducted and information provided to indicate coordination of activities with utility owners having facilities within the project limits. The schedule shall conform to the utility adjustment schedules included in the contract documents unless changes are mutually agreed upon by the utility company, the contractor and the FDOT.

7. The district scheduling engineer, with the involvement of the resident engineer, reviews the schedule. If it meets the contract requirements, he submits it to the district construction engineer for approval.
8. If the schedule submitted is determined to be inadequate by the FDOT engineer, it will be returned to the contractor for revision. The contractor will have 15 calendar days from the date of transmittal to submit a correct schedule.
9. The contractor shall submit an update work progress schedule when requested by the FDOT engineer. If revisions are required to be made to the working schedule, the contractor shall furnish revised charts and analysis within 21 calendar days after being notified by the FDOT.
10. The FDOT establishes contract time in calendar days for each project based on the type and volume of the work to be performed. In setting the time, the FDOT considers weekends and holidays. Also, the anticipated affect of utility adjustments or relocations on project progress is considered. Under the calendar day concept, every day that comes along is a

chargeable day (unless contract time has been suspended).

11. In addition to receiving payment for partially completed items of work, the contractor will also receive partial payment for materials and components delivered to the project or in the immediate vicinity of the project. Items eligible for partial payment include structural steel, precast drainage structures, precast-prestressed concrete elements, drainage, electrical, sign, aggregates, base course material and certain metal materials.
12. Certification by the contractor that he has paid his subcontractors their proportionate share from the last progress payment is required each month at the estimate time.
13. The contractor is required to furnish a testimony that all motor vehicles operated or caused to be operated on the project are registered in the state where the work is performed before any progress payments are made.

Highway Construction Permits Requirements

Highway construction projects may interfere with the environment adjacent to the construction site. Contractors are required to obtain a number of Federal, State and local environmental permits before any work can proceed. Some of

the different types of permits that might be required depending on the type and the location of the construction project are shown in Table 2-1. Other types of permits that might be required during highway construction projects were suggested by highway construction experts during interviews (see Appendix A: 1.g., 2.d. and 3.b.).

Highway Construction Performance Specifications

The FDOT has developed a standard specifications for highway construction and maintenance performance. These specifications include the directions, provisions and requirements that contractors have to follow in performing the work required by the contract. Some of the provisions and requirements that might affect the progress of the construction schedule are listed in Table 2-2.

Summary

An overview of construction scheduling practices was addressed in this chapter. Construction schedule's definition, purposes and objectives were illustrated. The different types of recognized scheduling techniques including the CPM (the most recognized method in construction scheduling) were reviewed. The concept of planning the construction schedule was discussed as well as the parameters that govern the planning and the preparation of a construction schedule. The properties and the information pertaining to the construction activity as part

TABLE 2-1. TYPES OF HIGHWAY CONSTRUCTION PERMITS THAT MIGHT BE REQUIRED FOR THE DIFFERENT TYPES OF PROJECTS.

Type	Permits
Federal	a. Corps of Engineers structure, dredge and fill permits for work affecting navigable waters. b. Coast Guard structure permits for all works affecting navigation in any significant way.
State	a. Dredge and fill permit. b. Source of pollution construction permit. c. Coastal construction line permit. d. NPDES/EPA permit.
Local	a. Surface water distribution permit. b. Water quality permit. c. Navigation permit. d. Land use plans permit.

SOURCE: FDOT Construction Manual, Fourth Edition, 1987.

TABLE 2-2. PROVISIONS AND REQUIREMENTS THAT MIGHT AFFECT THE PROGRESS OF THE CONSTRUCTION SCHEDULE.

Number	Provisions
1	External constraints should be considered, including site access, work of other contractors, local climate and environmental conditions, working schedules of local supplies, contract milestones, etc.
2	Prior to starting the clearing and grubbing operations, the project engineer should check that all permits, property rights, waivers, archaeological clearances and property easements have been obtained and are in order.
3	Before placing base material, the inspector must be sure the subgrade meets the following requirements: - Is firm and unyielding - Has passed bearing tests - Meets grade and cross section - Has the required density.
4	Before priming the base, the base must be permitted to cure before the prime coat is applied. The moisture content must not exceed 90% of the optimum moisture at the time of priming.
5	Asphalt plant operations should never be started until the weather conditions at the lay-down site are suitable for placing the mix, etc. Temperature should not be less than 40 F or more than 120 F.
6	If wind is blowing to the extent that dust, fine sand, and debris are being deposited on the tacked surface that is being paved, then operation should be ceased.

7	The wind factor during cold weather has a significant influence in the roller not to obtain the desired density, or roller marks cannot be removed because of the additional "chill factor" from the wind.
8	If the construction work requires narrowing the existing road or highway with concrete barricades, the length of the narrowed road or highway must not exceed the specified limit in length by the contract. If the construction work involves more than the specified limit in length, the work must be divided in sections and scheduled in different times.
9	The contractor shall not open up work to the prejudice of work already started, and the FDOT may require the contractor to finish a section on which work is in progress before work is started on any additional section.
10	The contractor shall always conduct the work in such manner and in such sequence as to insure the least practicable interference with traffic.
11	The contractor should schedule his work to minimize being in areas where heavy equipment is used or where operations are concentrated in a relatively small area to provide safety toi his employees and the adjacent traffic.

SOURCE: FDOT Construction Manual, Fourth Edition, 1987.

of the CPM network were explained. The different types of construction activities including task, procurement and submittal activities were defined. Guidelines for estimating activities' durations and steps for calculating contract's duration were presented.

An analysis of construction schedule's attributes was also performed. These attributes included of activities' codes, unit measures and descriptions, construction activities' constraints, the critical path, the overall completion date, subcontractors' participation in schedule preparation, activity's cost, weather sensitive activities, milestones, activity's float and front-end loading practice.

A comparison between highway construction schedules and building constructions schedules was performed. The guidelines developed by the FDOT for its engineers to review contractors' schedules, FDOT performance specifications and the different types of construction permits are illustrated.

CHAPTER 3
SCHEDULE MONITORING

Introduction

A major false perception in the construction field is that detailed planning and scheduling available through project management techniques such as the CPM will result in proper schedule control. While it is very unlikely that the actual activity duration will be exactly as estimated, it is also unlikely that the actual construction sequence will be exactly as represented in the logic diagram. Furthermore, there may be additions or deletions to the scope of a construction project that will affect the times that tasks can be started and completed.

Therefore, dependence on the original project schedule, throughout the duration of the project, especially after changes have been realized, is a very misleading handling of project execution and control.

Schedule Monitoring

Schedule monitoring provides a clear indication of schedule performance and is reflected in the time performance ratio calculations. The planned schedule serves as the benchmark of time performance. The actual schedule

is maintained independently of the planned schedule and updated frequently based on actual performance data.

In the construction industry, the contractor and the owner have a vital interest in knowing the overall project completion status. If the project is behind schedule, both parties should be concerned about what can be done to get the project back on schedule. During the course of the contract, the owner makes periodic progress payments to the contractor and it is customary for contractors to submit invoices at fixed intervals once a month to collect these payments. In these invoices, the contractor will claim that he/she has completed some specified percentage of the total project work. His/her claimed earnings are equal to the claimed percentage completed multiplied by the contract amount. The owner will review the contractor's claims. If the owner finds them reasonable, he will make a partial payment to the contractor, often retaining some percentage of the claimed earnings until the project is completed (Willis, 1986).

Monitoring or evaluations of the construction schedule on a periodic basis also provide other benefits. Such evaluations show that the owner has a concern for the degree to which the project objectives are being achieved. These evaluations also identify any weaknesses in the management part.

Updated schedules must be reimplemented whenever significant variances related to job conditions occur. As the job advances, a schedule recording actual performance is being produced. Since there will be differences between the planned schedule and the actual schedule, the data acquisition processes on actual performance become especially important. With the variances between the planned and the actual start and completion dates on each activity noted, the historic performance data are inserted into the actual logic network diagram in place of the planned performance data, and the actual schedule is recalculated.

Project's Periodical Summaries

Prior to the schedule monitoring, a project should be summarized in terms of dollar value, duration, construction method, type of contract, liquidated damages, degree of criticality, notice to proceed, and completion date. The project's periodical summarries or reports should give special attention to the status of the following groups of activities (Pierce, 1988):

1. Status of critical activities: This group of activities should immediately be examined to determine their status since failure to keep them on schedule will delay the project as a whole.

2. <u>Noncritical activities that are late in starting</u>: The problem with activities that start late is that they are more likely to finish late. This is true for reasons other than the obvious. The problem is that late-starting activities also tend to progress more slowly than they should. It is quite common to see activities that start before the late start date, which is acceptable, but then end finishing beyond the late finish date.
3. <u>Activities with low production rate</u>: A related problem is activities that start on time, but are proceeding more slowly than planned. Early on, their progress may seem fine, but their duration may be extended, undetected, until beyond late finish.
4. <u>Delays in resource delivery</u>: Most delivery delays are grounds for extensions of contract time. However, the fact of the delay must be recorded and its effects shown in the schedule. Most schedules use constrained dates to reflect material deliveries, or use a separate chain of activities for each major item. It is, therefore, good practice to check every constrained date or major material item on the

project at the time of each update and control cycle.

5. <u>Activities with more downstream</u>: Any activity that either starts late or shows a low rate of progress must be carefully watched. This is particularly true if there are more activities of the same type occurring later in the project. It may then be necessary to improve the productivity to sustain the durations of similar activities downstream, so that the schedule remains realistic.

Monitoring Process

There are three cycles within the planning and scheduling process that are repetitive in nature and are essential to integrated cost and schedule control. These cycles are the following (Muller, 1986):

1. The scheduling cycle of work that establishes the basic project strategy.
2. The production cycle of work that involves an implementation of the schedule.
3. The monitoring cycle of work.

The monitoring process of a construction schedule consists of the following steps (Pierce, 1988):

1. <u>Progress measurement</u>. It is primarily a process of collecting detailed data on the work, then

processing it to arrive at an accurate representation of the current job status.

2. Comparing progress to goals. The actual progress on the job is compared to the progress planned in the original schedule. The project team uses this information to measure the impact of the actual progress on the project as a whole.

3. Taking corrective action. The project manager corrects any schedule problems by applying more resources and/or by reexamining the job logic. Before applying corrective action, the expected finish time for each activity must be determined using one of the different methods explained in schedule updating.

Schedule Updating

The contractor should revise the schedule when it no longer accurately represents his/her plan for completing the remaining work. This is called schedule updating. He also should revise the schedule when the actual progress has not kept up with the schedule. Ordinarily, only the durations and/or the logic of the remaining activities will be changed. Shortened durations imply the assignment of the following methods (Ritz, 1990):

1. Improve productivity.
2. Increase staff.

3. Work overtime.

4. Reduce the work.

5. Subcontract part of the work.

The assignment of the above methods should not increase in contract price or the value of the various activities if the need for schedule updating stems from contractor-responsible causes.

There are several reasons that compel management to update the construction schedule. Two of these reasons are the following (Willis, 1986):

1. Contract duration is significantly modified by time extensions or supplemental agreements. The updated schedule shall be marked "revised" and bear the latest revision date and reason.

2. Variance report from schedule monitoring shows significant slippage and project manager does not agree with such slippage. At this time, it is necessary to incorporate into the construction schedule what the project manager knows that is not currently reflected in the schedule.

The goal of schedule updating is to determine the current status of the project. In order to determine the current status of the job, a two-step process is necessary and must be taken in order. The two steps are (Pierce, 88):

1. Measure the progress of each activity and its anticipated duration individually. It is important to update all activities before attempting to update the project as a whole.
2. Measure the impact of the activity progress on the project as a whole. This is done by recalculating the forward pass and backward pass, and then determining a new overall job duration.

To predict the impact of a particular activity's unexpected performance on the in-progress schedule as a whole, the expected finish for that activity must be determined. The three recognized methods in the construction industry for determining present status and expected finish for each activity are the following (Pierce, 1988):

1. <u>The percent complete method (PCM)</u>: It involves determining how much of the total work is complete, calculating a rate of progress per day, and then extending this value to determine an expected finish. The problem with the PCM is it tends to fall short primarily because detailed and accurate determinations are very seldom made for the actual work done. Usually, the percent complete is simply estimated, typically in 10% increments. As a result, the

alculated expected finish may be even more inaccurate. Even when fairly accurate calculations are made, the production rate is often variable, or may be affected by stops and starts. The steps for measuring the percent completion for an activity are shown in Table 3-1.

2. Remaining duration method (RDM): The second method of determining an activity's present status and expected finish is called the RDM. The number of remaining work days is estimated and this figure is added to the data update to determine the expected finish. The problem with this method is that the estimate of the remaining duration can be anything from an educated guess to a carefully calculated figure based on field data. Unfortunately, field data are rarely recorded completely and accurately.

3. Expected finish method (EFM): The third method of determining the present status and expected finish for an activity is called the EFM. The expected completion date is entered as a value. It is an appropriate method where the project manager has a good reason to believe an activity especially difficult where both an expected start and an expected finish are involved.

TABLE 3-1. STEPS FOR MEASURING PERCENT COMPLETE FOR AN ACTIVITY.

Number	Procedures
1	Spread the total cost for each direct activity code in the estimate over the time shown on the corresponding bar graph of the construction schedule. This distribution is not made uniformly. It should take consideration the need for a gradual buildup of manpower, engineering drawings, and an overload of materials.
2	Using the control estimate of hours for each direct account, a weight factor WF for each account can be calculated as follows: WF = Tot. est. hrs. for account/Tot. est. hrs. for project.
3	The cumulative percent complete for each code for each month of the project should then be calculated.
4	The monthly forecasted cumulative percent complete is then equal to the sum of each individual account percent complete multiplied by the WF for that account.
5	List each account and its corresponding WF.
6	Examine and observe progress every month on each account code. Using the procedure established, tabulate actual physical progress. Physical progress is the percentage calculated by dividing the physical portion of the work completed by the total physical quantity scheduled to be built.
7	After tabulating the physical progress for each account code, these are then combined with the corresponding WF and added up to a total percent representing the physical state of completion of the job.

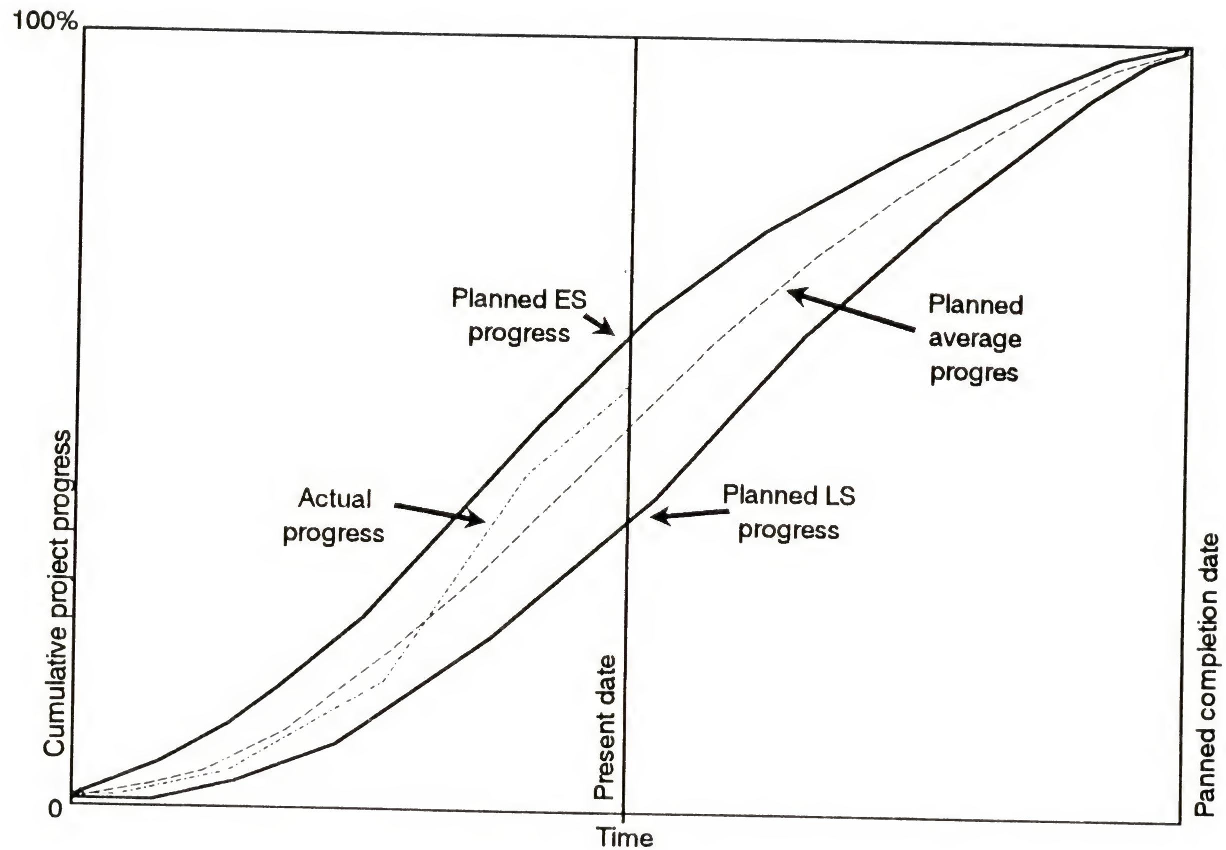
SOURCE: McGuire and Wynant (1989).

Also, the further the expected finish is into the future, the more likely it is to be inaccurate.

The Progress S Curve and the Schedule Control

In order to control the project schedule, the project manager has to monitor the project progress against the time scale. The project is broken down into activities as a convenient way to check elements the work against time. In the same time, each activity has to be weighted for its percent of the total project. The weight is determined by the value of the human and/or the physical resources used to accomplish the task. The weighted value of the activity multiplied by physical percent completion tells us how much earned value that activity is contributing to the total percent complete. Conversely, the earned value divided by the total budget for that activity gives us the physical percent complete for that activity (Clough and Sears, 1979).

The procedure of plotting the planned progress curves is to produce two such curves. One curve is determined on the basis of all project activities starting as early as possible. The other is based on all project activities starting at their late start date. When these two curves are plotted, they form a closed envelope (Figure 3-1). An average curve is then sketched in between the two extreme curves. During the construction period, the actual progress



SOURCE: Clough and Sears (1979).

Figure 3-1. Progress S curve.

curve is plotted periodically. If the actual progress plots above the average progress curve, the time status of the schedule execution is considered to be satisfactory. When it lies below, schedule progress is considered to be unsatisfactory.

Unrecorded change orders, lack of owner's performance and unexpected events are justifying reasons forcing the actual progress curve below the planned progress curve. If these reasons are not the cause of the slower curve there must be another serious problem that causes the adverse trend, such as poor management.

Time Extension Justifications

According to FDOT specifications, time extensions may be granted by the FDOT state construction engineer on an evaluation of the district's recommendation. Such extensions of time may be allowed only for delays occurring during the contract time period or authorized extensions of the contract time period. Extensions of contract time will not be granted for delays due to the fault or negligence of the contractor. Whenever the work is suspended by the FDOT for reasons other than the fault of the contractor, allowance for any delay in completion of the work due to such suspension shall be made.

The following are valid reasons for granting a time extension (FDOT Construction Manual, 1987):

1. When a controlling item of work is delayed by factors beyond contractor's control that could not have been anticipated at the time of letting.
2. When the FDOT fails to fulfill contractual obligation such as submittal approval that delays controlling item of work.
3. Unreasonable weather conditions; time extension due to severe weather are justified only when rains or other inclement conditions or related adverse soil conditions prevent the contractor from productively performing controlling items of work resulting in:
    a. The contractor being unable to work at least 50% of the normal work day on predetermined controlling working items due to adverse weather conditions.
    b. The contractor must make major repairs to work damaged by weather.
4. Delay in delivery of materials: Delays in delivery of materials or component equipment which affect progress on a controlling item of work will be considered as a basis for granting a time extension if such delays are beyond the control of the contractor or supplier. Request for time extension will not be considered unless

the contractor furnishes documentation that his order was placed in a timely manner.

5. Delay in adjustment or relocation of utility that affects a controlling item of work. The affect of utility relocation and adjustment work on job progress will be considered as a basis for granting a time extension only if all the following criteria are met:

   a. Delays are the result of utility work not detailed in the plans that is not accomplished in reasonably close accordance with the schedule included in the special provisions.

   b. Utility work actually affected the progress toward completion of controlling work items.

   c. The contractor took all reasonable measures to minimize the affect of utility work on job progress. This includes cooperative scheduling of his operations with the scheduled utility work at the pre-construction conference and providing adequate advance notification was given to utility companies as to the dates on which their operations must be coordinated with the contractor operations to avoid delays.

6. If the amount of the contract is increased due to net variations in estimated quantities or due to work added or unforeseeable work.

Schedule Acceleration

The project schedule is a plan of work per unit time, so it is somewhat flexible. By speeding up the task we can make up for past or future lost time and still make the predetermined schedule date. Therefore, the work is flexible and must be controlled to the inflexible time scale. In highway construction industry, especially with large projects, schedule acceleration provision is required. Schedule acceleration is employed when projects must be completed by a certain date or there are special considerations related to traffic's congestion or high public visibility. In order to compensate for schedule delays, the schedule could be accelerated by performing a job acceleration analysis based on time/cost trade-off. Table 3-2 shows the guidelines that should be followed in schedule acceleration (Hamburger, 1989).

Liquidated Damages

For all the days over the adjusted contract time that it takes the contractor to complete the project, liquidated damages are charged per day against the contract. Adjusted contract time includes time added or granted by supplemental agreements, granted time extensions and overrun in contract

TABLE 3-2. SCHEDULE ACCELERATION PROCEDURE.

Number	Procedure
1	Activity with the longest duration in the critical path should be considered for crashing.
2	Determine if sequential critical activities can be performed concurrently.
3	Work double shifts for strictly sequential activities.
4	In general, work to be accelerated belonging to a general contractor will be easier to control than that belonging to a subcontractor.
5	Determine the cost of further delays.
6	Apply acceleration to early activities whenever possible. As a rule, early project activities are easier and less costly to compress than the later ones. Later activities either have greater personnel requirements or employ trades or skills that commands premium pay for overtime.
7	Favor early acceleration over late acceleration so that the schedule reduction potential of the activities at the end of the project can be saved for later use.

SOURCE: Hamburger (1989).

amount. The liquidated damages represent the added costs for project administration and inspection, also for the lost utilization of the facility. The amount charged for each day is specified in the contract and depends mainly on the dollar amount of the contract (FDOT Construction Manual, 1987).

Suspension of Contract

Suspensions are appropriate when work in a project must cease due to conditions beyond the contractor's control, and a substantial amount of work remains to be accomplished. Such conditions are (FDOT Construction Manual, 1987):

1. Inability to obtain delivery of major items of customized equipment.
2. Extra work authorized late in the contract that requires off site fabrication.
3. Diverting contractor's work force from a project to complete a more critical one.
4. Prime contractor vacations.
5. Extremely adverse weather conditions such as hurricanes, flooding, catastrophic occurrences, etc., which are anticipated to cause extended delays.
6. Heavy traffic congestion associated with special events that are not identified in the contract

but are expected to cause hazardous conditions for the traveling public.

In-Progress Schedule Evaluation

To analyze the construction schedule during its progress, the owner's representative or the contractor may use the following guidelines to evaluate the in-progress schedule on hand (De La Garza et al., 1990):

1. Use current trends such as float consumption and duration usage to forecast the degree of success or failure to be expected in meeting future contractual milestones.
2. Any revised logic or durations may be developed by the contractor and/or the FDOT but must be approved by both parties.
3. If the variance report shows the project ahead of schedule, the owner should notice such gain, but should not commit the project to some future gain.
4. Do not change the logic of unfinished activities just because the project is ahead of schedule.
5. Determine whether the delay is likely to continue.
6. Do unfinished activities have anything in common, i.e., subcontractor, material, type, crew, etc., with the activities involved in the delay?

7. Make schedule projections based on the project's performance history.
8. The ratio of (days to makeup/total days remaining) should be less than 0.2.
9. The progress on an activity is assessed by calculating the expected real remaining duration.
10. Perform a consistency analysis between remaining duration, percent complete, and original duration. The consistency analysis consist of:
    a. If an activity shows 100% complete and still has remaining duration, it probably means that the work was already paid for, but there is still work left to execute.
    b. Update unfinished activities duration based on days remaining, as opposed to percentage complete.
11. Identify areas that need corrective action while there is still time for such action to produce a positive effect.
12. Projected duration to finish a job = ((100 x Actual Time)/Actual % complete) - Actual Time. Variance = original late finish--(current early finish or actual finish) is used as the indicator to flag lagging activities. This parameter compares the current schedule against

the original schedule. It is used instead of the total float, which only considers the current schedule, i.e., total float = (current float - early finish).

Productivity, percent = Budgeted hours/Actual hours.

Schedule Delays

Delays are periods of time during construction of a project in which work was not performed as originally anticipated at the start of the project. There are three types of delays; owner caused delays, contractor caused delays and Forced Majeure (act of God) delays (Beach, 1992). If there is a schedule slippage, the entire path to which the lagging activities belong should be marked for delay analysis. The analysis should identify the following (De La Garza et al., 1990):

1. If the delay is one delay or a combination of delays.
2. If there has been an "ongoing" delay, or whether it has been independent.
3. Whether the delay is likely to continue.
4. Do unfinished activities have anything in common, i.e., subcontractor, material, type, crew, etc., with the activities involved in the delay?

Changes in the current construction schedule definitely imply different logic and/or activities' durations. To extend the duration of critical unfinished activities based on the progress of the project to this point, the logic of other activities should be modified to compensate for such delays. Make sure that previously authorized time extensions are reflected in the schedule.

Contract Change Orders

Change orders document changes from the original scope of the contract, confirm schedule revisions and set forth other modifications. They are issued whether or not the amount of compensation to be paid to the contractor will be affected (Barrie, 1984). To estimate the effect of a change order on the progress of a construction schedule, the current status of the work and the contractor's approved plan for completing the remaining activities must be known. The change order's time effects can be observed by comparing the current approved plan to the plan generated after the changes to the network have been processed. At this point, it is known whether the change order would delay the completion of the remaining work, and if so, the length of the delay. This analysis will show those activities affected both directly and indirectly by the change order. The estimate of the dollar amount must take both type of effects into consideration. The estimate must also consider that time has value, whether it is on the critical path.

When a change order occurs, the time factor for the modification can be unilaterally defined by identifying the network activities whose dollar value or durations are affected (De La Garza et al., 1990).

Summary

In this chapter, the concepts of a schedule's monitoring and updating in finishing the construction project on time were addressed. The types of information that should be included in the periodical report of the project progress were discussed. Progress measurement, comparing progress to goals and taking corrective action, as stages of the monitoring process, were presented. The three methods employed to determine the present status and the expected finish for the construction project activities were demonstrated. These three methods are the percent complete method, the remaining duration method and expected finish method. The progress S curve as a tool to control and monitor the schedule was demonstrated. Reasons for justifying time extension by the FDOT were elaborated. The procedure for accelerating the project duration was also discussed. Liquidated damages and suspension of contract time as special conditions of construction projects were briefly discussed. For the rest of the chapter an analysis of regulations for monitoring highway construction schedules was performed. These analyses include in-progress analysis, delay analysis and change order analysis.

CHAPTER 4
KNOWLEDGE-BASED EXPERT SYSTEMS TECHNOLOGY

Introduction

KBES represents the first step in a process that is poised to transform computing by moving programming technology beyond numerical programming into logical and symbolic programming. KBES technology comes from a branch of computer science that is called artificial intelligence (AI). AI is concerned with a broad range of topics that are related to simulating human intelligence in a computing machine. These topics include natural language processing, robotics, cognitive modeling, machine vision, heuristic problem solving, knowledge representation, and expert systems (Maher, 1987).

There had been several efforts in defining expert systems, the most popular definitions are the following:

1. "An intelligent computer program that uses knowledge and inferences' procedure to solve problems that are difficult enough to require significant human expertise for their solution" (Feigenbaum, 1981).
2. "An interactive computer program incorporating judgment, experience, rule of thumb, intuition,

advice about a variety of tasks" (Gaschnig et al., 1981).

3. "An Expert Systems solves real-world, complex problems using a complex model of expert human reasoning. The system will reach the same conclusions that the human expert would reach if faced with a comparable problem" (Weiss, 1984).

4. "A model and associated procedure that exhibits, within a specific domain, a degree of expertise in problem solving that is comparable to that of a human expert" (Ignizio, 1991).

Therefore the KBES is an "interactive" program, playing the role of a human expert by utilizing heuristic knowledge. This allows the system to make educated guesses, recognize promising approaches, and narrow down the search process in a solution space.

KBES technology grants many conceivable advantages in various domains that require extensive human expertise involvement. Some potential advantages of a well-designed expert system over the use of human experts are shown in Table 4-1 (Ignizio, 1991).

Characteristics of Knowledge-Based Expert Systems

KBES features many characteristics that differentiate it from traditional programs. These characteristics are as follows (Adeli, 1987):

TABLE 4-1. ADVANTAGES OF WELL-DESIGNED EXPERT SYSTEMS.

Number	Advantages
1	Always and instantly available, and always performs at the same level of the expertise.
2	Has direct and instantaneous access to the necessary databases and is not bound to the limited, biased, and imperfect collections of the human.
3	Logical, objective, consistent, and thus does unswayed by emotional arguments that might influence a human.
4	Doesn't forget or make mathematical errors.
5	Is in a constant state of awareness. It will not overlook any critical events that it has been assigned, and has the means to monitor.
6	Makes its decisions with regard to the goals of the firm rather than with regard to how such decisions might influence its persona promotions or pay raise.
7	Multiplies the expertise of the firm, that is, it is directly accessible by all other divisions of the firm whereas the human expert's access is limited by physical and geographical considerations.
8	It is a repository for the storage of the knowledge of those experts from those experts from whose input it was developed; it is a knowledge bank of considerable value and is thus a tangible, permanent asset of the firm.

SOURCE: Ignizio (1991).

1. They are knowledge-intensive programs.
2. They use heuristic in a specific domain of knowledge to improve the efficiency of search.
3. In a KBES, expert knowledge is usually divided into many separate independent rules. The knowledge representation is clear and rather easy to read and to understand.
4. The knowledge base used in a KBES is usually separated from the method of applying the knowledge to the current problem. These methods are called inference mechanism.
5. They are usually highly interactive.
6. The output of an expert system can be qualitative rather than quantitative.
7. They tend to imitate the decision-making and reasoning process of human experts. They also can provide advice, answer questions, and justify their conclusions.

Limitations of Knowledge-Based Expert Systems

Because expert systems technologies is considered new and remains under development, at the present stage they suffer from the following (Adeli, 1986):

1. They do not learn.
2. They lack common sense and feeling.
3. Their performances deteriorate fast near the boundaries of their expertise.

4. Most expert systems today lack a user-friendly natural language interface and are not easy to use by nonexpert.
5. Many of them require expensive dedicated artificial Intelligence machines for efficient operation.
6. They have a problem of capturing rare expertise.
7. They are suitable for problems involving deduction and not so much for problems involving induction or correlation.

In the last decade, KBES had been applied in limited fields and areas. In the near future, KBES technology is expected to be implemented in many different fields and practices. Currently, existing types of KBES applications are displayed in Table 4-2. (De La Garza et al., 1990).

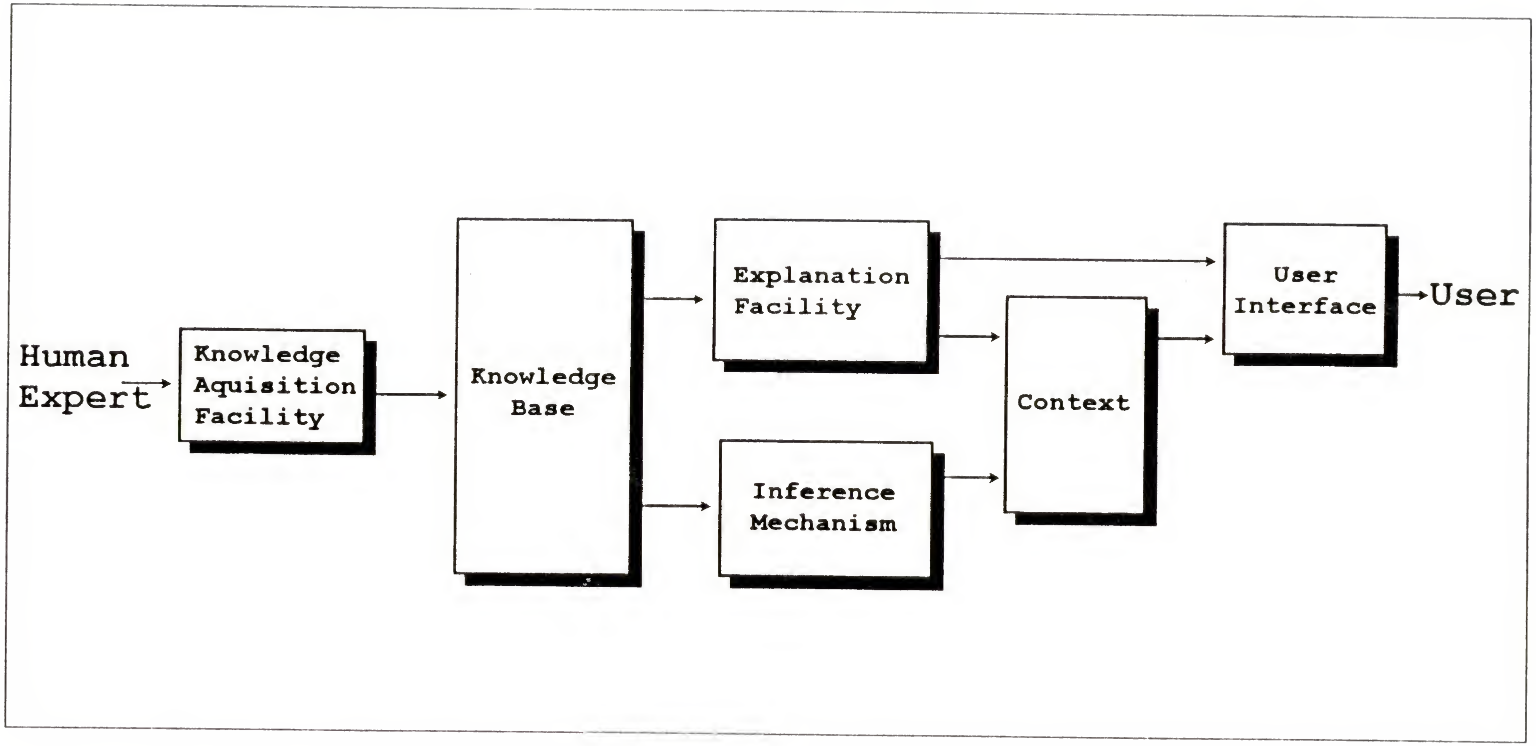
Architecture of Knowledge-Based Expert Systems

The basic architecture of a KBES features a separation of domain knowledge, control knowledge, and knowledge about the specific problem being solved. This leads to the identification of three basic components of a KBES, the knowledge base, the context, and the inference mechanism. Additional components needed to make the KBES more usable are a user interface and an explanation facility. To enhance extensibility, a knowledge acquisition facility is desirable. The relationship between the KBES components is illustrated in Figure 4-1.

TABLE 4-2. EXISTING TYPES OF KBES APPLICATIONS.

Type	Description
Prediction	A prediction application would be a KBES for forecasting construction cost and time from existing project conditions.
Diagnosis	Diagnosis KBES locate malfunctions from observed and interpreted data. A KBES for criticizing and comparing construction schedules is an example.
Design	A design KBES application consists of developing a configuration for an object that satisfies all applicable constraints. The automatic generation of conceptual and detailed design specifications for a construction project is an example.
Planning	A planning KBES explores possible future actions to produce a series of feasible steps leading to a desired goal. An example in this category would be the automatic or interactive generation of construction schedules.
Monitoring	A monitoring application is one in which a KBES examines real-time data and compares the observations with planned behavior to determine defects in the plan and malfunctions of the system. A KBES for explaining the reasons for lagging construction falls in this category.
Instruction	An instruction KBES plays the role of teacher to a student by diagnosing the student's problem areas from errors in his solutions to exercises. A KBES for teaching the fundamentals of bidding construction projects is such an example.
Control	A control KBES encompasses many functions of the applications previously described. It would be theoretically possible, for example, to design a KBES to coordinate all construction's project management functions for a specific type of building.

SOURCE: De La Garza, East and Yau. (1990)



SOURCE: Adel (1988).

Figure 4-1. Architecture of expert systems.

The components of the KBES are further described in the following statements (Maher, 1987):

1. <u>Knowledge base</u>: The knowledge base is at the very heart of the expert system. It is the repository of information available in a particular domain. The knowledge base may consist of well-established and documented definitions, facts, and rules as well as judgmental information, rules of thumb, and heuristic rules. The facts within the knowledge base represent various aspects of a specific domain that are known prior to the exercise session of the expert system.
2. <u>Inference mechanism</u>: It controls the reasoning strategy of the KBES by performing two primary tasks. First, it examines the status of the knowledge base and working memory to determine what facts are known at any given time, and to add new facts that available. Second, it provides for the control of the session by determining the order in which inferences are made.
3. <u>Context</u>: It is a temporary storage for the current state of specific problem being solved. Its content changes dynamically and it includes information provided by the user about the

problem and the information derived by the system. The context contains facts that have been determined for a specific problem under consideration during the exercise session. The results of the inference process are new facts and these facts are stored in the working memory.

4. Explanation facility: The explanation facility is attached with the input-output interface. It provides answers to questions, justifies answers and guides the user to use the system effectively and easily.

5. Knowledge acquisition facility: Knowledge acquisition is the process by which expert knowledge is obtained from various sources. Knowledge acquisition facility facilitates the structuring and the development of the knowledge base.

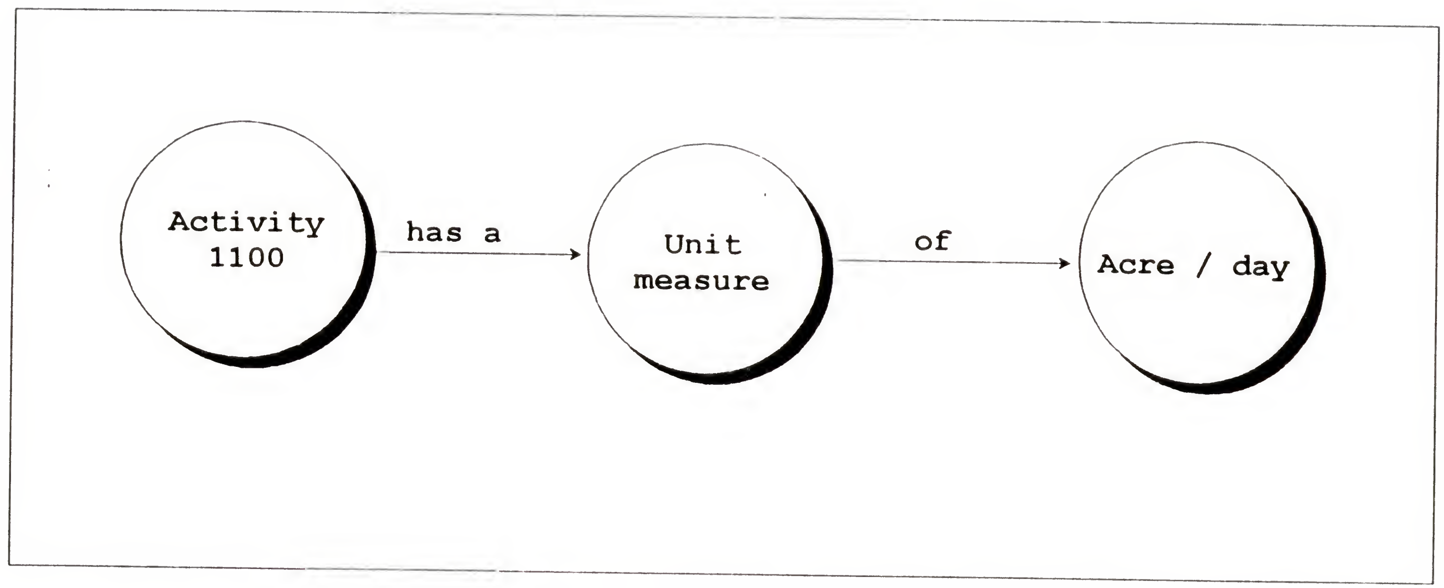
6. User interfaces: It allows the user to interact with the KBES and question it. Access to the knowledge base for information utilization is governed by the user interface. User interface may include natural language processors, menus, multiple windows, icons, or graphics.

Knowledge Representation

Several modes or types of knowledge representation could be implemented to convert expertise or knowledge to a language that could be understood by the expert system environment. These modes include object-attribute-value (OAV), semantic networks, frames, logic programming, rule-based system.

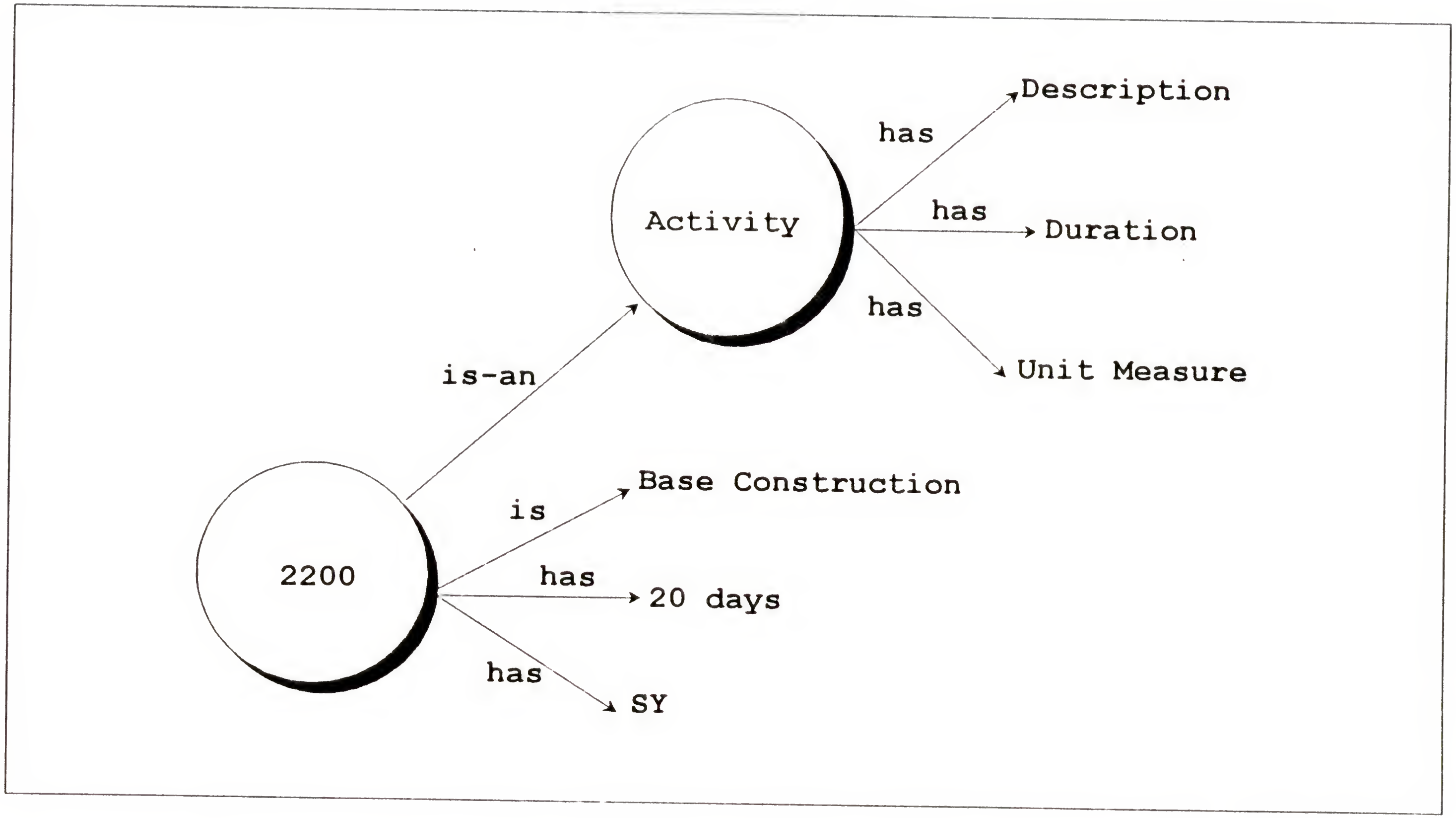
In the following paragraphs, a brief description of each mode is discussed except for the rule-based system which will be reviewed in detail and will be the mode employed in this research expert system.

1. OAV Triplets. OAV triplets represent certain facts within a knowledge base and may be extended to provide the basis for the representation of heuristic rules. Each OAV triplet is concerned with some specific entity or object (Ignizio,1991). In Figure 4-2, the object is activity log, the attribute is the unit measure, and the specific value of the unit measures is acre/day.
2. Semantic Networks. A semantic network is composed of multiple OAV triplets in network form as illustrated in Figure 4-3. Semantic networks are used to represent several objects and several attributes per object.



SOURCE: Ignizio (1991).

Figure 4-2. OAV triplet representation.



SOURCE: Ignizio (1991).

Figure 4-3. Semantic network representation.

3. <u>Frames</u>. A frame contains an object plus slots for any and all information related to the object. The contents of such slots are typically the attributes, and attribute values, of the particular object. In addition to storing values for each attribute, slots may contain default values, pointers to other frames, and sets of rules or procedures that may be implemented. Figure 4-4 Illustrates a frame-based representation of an object.

4. <u>Logic statements</u>. The most common form of logic is that known as propositional logic. A proposition is a statement that may be either true or false. Proposition may be linked together with various operators such as AND, OR, NOT, EQUIVALENT. As an illustration, consider the statements X, Y, and Z where X and Y are true while Z is false. Thus we may conclude that:

   X AND Y is true

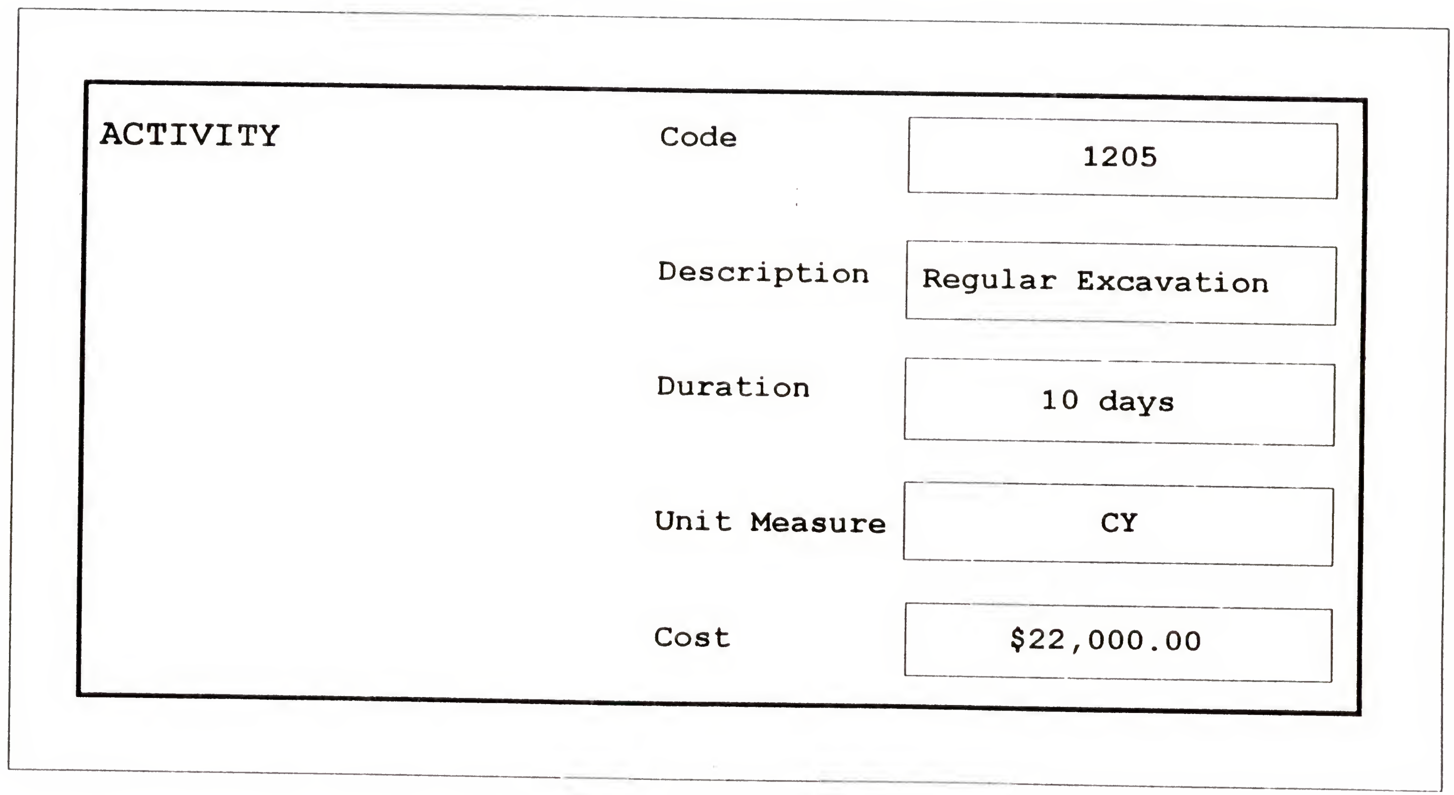
   Y AND Z is false

   X OR Z is true

   NOT Z is true.

<u>Rule-Based System Representation</u>

Rule-based system representation is the most popular mode of knowledge representation within expert systems.



SOURCE: Ignizio (1991).

Figure 4-4. Frame-based representation.

Rules are also referred to as IF-THEN, or production rules. The reasons for selecting the rule-based expert system for this research, other than its popularity and its wide use, are the following:

1. It can be run on a personal computers.
2. The natural simplicity of representing knowledge.
3. Additions, deletions, and revisions of rule bases are straight forward processes.
4. Validation of the content of rule-based systems is relatively a simple process.

A production rule of the rule-based system contains a premise-conclusion statement. These are represented by IF-THEN-ELSE clauses. The general format for production rules and some demostrated examples are shown in Figure 4-5 and Table 4-3.

Each typical production rule has several properties including name, premise, intermediate conclusion, conclusion, notes, references, and confidence factors. Each property is defined in the following paragraphs (Ignizio, 1991):

1. Name. Each rule should have a distinct and a descriptive name. Rather than just labeling a rule by a number or letter, it is better to label the rule by a name that describes the purpose of the rule.

RULE #

IF

Conditions

THEN

Conditions and Choices

ELSE

Conditions and Choices

NOTE: ______________________________

REFERENCE: _________________________

SOURCE: Ignizio (1991).

Figure 4-5. General format of an IF-THEN-ELSE (production) rule.

TABLE 4-3. EXAMPLES OF IF-THEN-ELSE (PRODUCTION) RULES.

Rule Type	Rule Format
General Requirement Rule	IF Activity number is 1200 THEN Activity description is regular excavation REFERENCE The coding system as suggested by the researcher.
Time Rule	IF Activity number is 1200 and 1,300,000 CY <Volume >300,000 CY THEN Regular excavation production rate is production rate = 0.0000367 Vol. + 61/Day ELSE For Vol. >300,000 CY and <1,300,000 CY production rate = 0.0000367 Vol. + 61/Day NOTE For Vol. >1,300,000 CY production rate = 27,500 CY/Day REFERENCE Florida Dept. of Transportation, production rates for estimating working days, June 1989.

2. <u>Premise</u>. Every rule consists of one or more premise clauses. The complete set of premise clauses is termed the rule premise.
3. <u>Intermediate conclusions and conclusions</u>. A intermediate conclusion is one that is the conclusion clause of one rule while also serving as a premise clause for another. A (final) conclusion is one that does not appear as a premise clause for any other rule.
4. <u>Notes and references</u>. Notes and references are essential for the documentation of each production rule. They help the user during the exercise or the consultation session to know the reason and the source of the rules.
5. <u>Confidence factors</u>. When uncertainty is employed, confidence factors are associated with each rule. The confidence factor of a rule's conclusion is a function of the confidence factors of the rule and the rule premise.

The conditions in the IF part are statements (text or algebraic) which may be true or false. The KBES tests these conditions against the data provided by the user. The THEN part can be a series of conditions as well as choices. But unlike the IF conditions, these are factual statements

and not tests. The THEN and ELSE conditions may also include statements that assign a mathematical expression to a variable, allowing values to be calculated during a program session and, optionally displayed at the end of a run. The NOTE part is added to a rule whenever it is desirable to provide some special information to the user. Similarly the REFERENCE part of the rule is intended for the user's information only and has no effect on the program. It helps the user find the source of knowledge contained in the rule (Ahmed ,1993).

Inference Mechanism and the Search Strategies of Knowledge-Based Expert Systems

The purpose of an expert system is to develop and recommend a solution to a given problem. To accomplish this task, the expert system must conduct a search for the solution; and it is the responsibility of the inference mechanism or inference engine to perform the search an efficient and effective manner (Ignizio, 1991). In the search process the expert or the engineer is faced with a number of alternatives and a variety of constraints. Constraints serve to filter out the number of choices from which the user will make his selection. Search alternatives include backward chaining, forward chaining, and (in some advanced expert systems) a mixture of both backward chaining and forward chaining. The following are definitions of the two search alternatives:

1. <u>Backward chaining</u>. Backward chaining is a term used to describe a technique in which an expert system automatically check all of the rules to see if the there is one that could provide a needed information. The program will then "chain" to this new rule before completing the first rule. This new rule may require information that can be found in yet another rule. The program will then again automatically test the new rule. The logic of why the information is needed goes backwards through the chain of rules.
2. <u>Forward chaining</u>. Forward chaining is the alternative to backward chaining. It is used for a technique of testing the rules that is not goal driven. In forward chaining, rules are simply tested in the order that they occur. If information is needed, other rules will not be invoked. Instead, the user will be asked for the information.

<u>Existing Knowledge-Based Expert Systems Technology in Construction Management and Scheduling</u>

Because most construction management and scheduling software lack the ability to interpret qualitative or subjective information, researchers made several attempts to

investigate the use of knowledge based expert systems in solving these problems.

Niwa (1984) reported an expert system called the Project Risk Assessment System. This expert system was developed by Hitachi System Development Laboratory for large construction projects. This system focuses on the project execution stage and attempts to identify risks and risk countermeasures and then mapping these to standard work packages.

Nay and Logcher, 1985, defined an expert system framework for analyzing construction project risks. This framework is based upon the difference risk occurrences that can be associated with a work package.

McGartland and Hendrickson, 1985, discussed how expert systems can be applied to scheduling, time control and cost control. They explored the factors that characterize the domain of KBES in any field, which explained the obvious need for implementing KBES technology to analyze and evaluate construction project scheduling. These factors are

1. Algorithmic methods are either not feasible, too cumbersome or too restrictive.
2. There are recognized experts in the field.
3. The task requires from ten minutes to a few days when performed by an expert.

4. The task is primarily cognitive with reasonably high level concepts or objects involved.
5. The task has significant payoff.

Levitt and Kunz (1985) explained an expert system that deals with theoretical and experience-based knowledge of a construction activity. The risk factors that could impact the duration of planned activities were classified as favorable or unfavorable. Their effects were then projected on the duration of unfinished activities assuming the risk factors continued to be favorable or unfavorable. Such an expert system exercised project control by generating a meaningful update of the schedule using explicit knowledge about both the particular construction domain and various project management techniques.

Kunz et al. (1986) discussed "What if" scenarios that form the basis for exploring, merging and eliminating hypothetical alternatives, and how they could be used in the construction domain. The proposed system represents anticipated contingencies, such as different combinations of soil types and labor conditions. The system then reasons about the factors' effects on the cost and duration of the project. The system allows distinction between choices, which are made with certainty by the user, and the implication of choices, where the user generally has incomplete knowledge about which of several possible

implications will actually occur. The use of contingent possibilities gives the user the opportunity to identify scenarios of interest and to realize the most favorable contingencies while minimizing the effect of less favorable ones.

Foster (1986) predicted KBES technology to have great potential in the future applications in construction project management area. He predicted that proper expert systems should reduce some day-to-day dependence on scarce experts allowing them to concentrate on more creative and important tasks. He illustrated three types of project management problems as a good example for KBES applications. These three are

1. Building project or sub-project networks.
2. Rule-based scheduling--using KBES to achieve better solutions.
3. Analyzing large amounts of project data letting the system perform functions for which adequate time and/or human resources do not exist.

Foster also highlighted that most ordinary programming systems create artificial constraints by their nature. This will force the user to build models that are not true presentations of real world situations. In contrast, expert systems should lend themselves to better and more natural problem representations and solutions. He

concluded that the development of KBES in construction might have great advantages. He expected that it will explore the possibility of finding weaknesses or omissions in the existing procedure. This will lead to a better procedure even if the KBES is never implemented.

Walmsley (1986) proposed a construction management decision support system, which aid in cost and schedule management of the construction of a nuclear power plant. The system is based on a multilayered expert system concept that minimizes delays and problems.

O'Connor et al. (1986) reported on the progress toward building an expert system for the analysis and evaluation of construction scheduling networks from an owner's perspective. This KBES is being developed by the U.S. Army Corps of Engineers (Construction Engineering Research Laboratory). The KBES has unique and advantageous features compared with other systems being developed for this problem domain. It relies on the timing of every schedule activity to make sound recommendations. The knowledge base consists of heuristic for the analysis of both initial and in-progress schedules for building construction (medium-rise to high-rise reinforced concrete buildings). The sources of construction scheduling expertise for the knowledge base were consultants, owners and contractors. The acquisition of the knowledge base for the system was done by analyzing textbook scheduling

knowledge, interviewing experts, and studying the experts' performance on specific problems.

This implementation takes advantage of the already available electronic databases generated by project management systems. This integration with an existing project management system is a unique and advantageous features compared with other systems being developed for this problem domain. The needs of contractors are more complex and sophisticated in their own way than those of owners. For example, contractors normally schedule to a finer level of detail and separate activities by subcontractors. These two conditions are typically ignored by owner. The software selected to implement the knowledge base was designed to be integrated by linking together database program (dBase III), a project's management package (Primavera), and expert system shell (Personal Consultant Plus).

Echevery et al. (1989) discussed the benefits that scheduling and planning tools in construction are receiving from the new techniques developed recently in different computer software areas. They also explained how knowledge based systems are applied successfully to the generation of construction schedules, for mid-rise building construction.

Alshawi (1989) described a facility that automates the establishment of construction solution from a given design solution. A prototype has been developed to generate

construction activities and their logic automatically. This is done by relying on the integration of expert systems technology, database and project management software.

Kartam and Levitt (1990) reported on SIPE, an expert system for interactive planning and execution. The system was used to model a construction plan for a multistory office building project. The system uses a frame hierarchy, generic operators and constrained-based approach to generate activity networks from a description of the components of a facility.

Chang and Ibbs (1990) discussed the importance of resource allocation to construction management. They also discussed the inability of some proposed expert systems to resolve the impacts of a variety of external forces on resource allocation optimization. Examples of these external forces are weather conditions and resource availability that are unfavorable to project management. They proposed the RALS algorithm that uses the output from an expert system called priority ranking. This algorithm uses possibility theory and the generalized *modus ponens* logic inference rule to determine priority ranking. The algorithm considers the impact of the external factor and allows the user to have significant input to the priorities applied to allocation criteria that are based on the considerations of both internal and external factors.

De La Garza et al. (1990) explained CRITEX, a system written for the Corps of Engineers with the purpose of analyzing construction schedules. They pointed out the reasons why the construction field is a good candidate for employing KBES technology as

1. Construction is an experience-based industry.
2. Construction decisions must be made in real time.
3. Construction decisions involve managerial issues.

They also discussed the different approaches of knowledge elicitation, which included

1. Published material review,
2. Structured interview, and
3. Observation of tasks and behavior with limited information.

Moselhi and Nicholas (1990) presented an integrated hybrid expert system for construction planning and scheduling. The system integrates through an expert system building tool (ESBT) a relational data base, knowledge base, and its control functions, a traditional network analysis software, and an interfacing program written in FORTRAN language. The prototype features modules that determine the job logic among activities and modifies activities' durations to realistic ones.

Benjamin et al. (1990) outlined the development of an expert system for construction planning and scheduling. They evaluated the system effectiveness in improving the productivity of inexperienced construction project schedulers. The prototype, developed using the M.1 knowledge engineering shell, incorporates data bases, algorithm, and heuristic. The study found inexperienced schedulers using the prototype recorded significant improvements in scheduling performance.

Chang and Ibbs (1990) stated that traditional logical methods or mathematical models in project scheduling are clumsy and difficult to apply to measure the impacts of external factors. Examples of these external factors are weather conditions, resource availability, material delays, etc. Consequently, these impacts have often been ignored in the resource allocation and project management processes. With this omission, schedules produced by the basic CPM/PERT and resource allocation procedures ignore the significant external factors that can negatively impact the project. This deficiency can be resolved with the help of recently developed expert systems. An expert system theory called PRIORITY RANKING proposed by Chang and Ibbs (1990) considers the impacts of the external factors on project schedules. Knowing the probabilities of each external factor and the activities that are candidates for resource assignment, PRIORITY RANKING will compute the priorities for the

candidate activities. Once the priorities have been determined, the schedule for the activities can be prepared according to these priorities.

A proposed KBES by (McGartland and Hendrickson, 1985) considered the cost control and the time control of the project schedule. This KBES is designed to verify the weekly input that will include

1. Estimated percent complete;
2. Expenditures to date;
3. Actual quantities of labor (man-hr);
4. Actual quantities of material, and
5. Actual quantities of equipment (hr).

The input also includes the actual start time and the actual finish time as planned. Based on the data base information and the knowledge base rules, this KBES decides whether the input is reasonable or not. It also calls attention of the user to undertake proper actions.

Terms and Definitions

Artificial Intelligence (AI): is the sub-field of computer science which is concerned with symbolic reasoning and representation of knowledge. AI methodologies have been widely and successfully used for developing expert systems.

Attribute: is the characteristic of a concept or an object, represented as a slot within a unit.

Domain: The domain of an expert system is the application it serves. For instance, an expert system might

serve the domain of mathematical problem solving, or the domain of financial planning, or the domain of construction scheduling.

Fact: is the fundamental unit of knowledge. For example, a fact might consist of the proposition "this car is red" which is declared to be "true" but only from the viewpoint "on Wednesday." On Thursday, we may find the car has been repainted.

Goal-driven: refers to backward chaining reasoning. Goal-driven processing starts with an explicit goal, matches the goal to rules or frames, and then attempts to prove or achieve the goal by providing or initiating the rule or frame.

Heuristic and Heuristic Programming: are rules that developed through intuition, experience, and judgment. They represent guidelines by which a system may be operated. They are not usually in the public domain but they evolve through years of experience and reside in the memory of an individual. The main characteristic of many heuristic rules is to reduce the number of alternatives that are considered. Heuristic programming, in the other hand, involves finding a solution to a problem using operations from a given set of operations. The solution is produced in a finite number of such operations. Both heuristic and heuristic programming are used to enhance one's decision making procedure. They

form a portion of the tools incorporated into decision support system.

Hybrid AI Development Tool: is a system which allows the user to employ different AI methodologies for representing knowledge, reasoning with that knowledge and explaining the domain and the problem-solution process to users.

Inference: is the step in building a logical chain, usually expressed as "IF" this true, "THEN" that must be true also.

Representation: is the process of describing knowledge in ways which can be used by the computer for reasoning and which can be communicated to the knowledge representation include frame-based representation of description of concepts and objects, rule-based representation of heuristic knowledge, and descriptions of algorithms within a programming language such as LISP.

Summary

In this chapter a brief commentary of expert systems and its characteristics were presented. The commentary includes distinguished definitions and characteristics of expert systems, advantages and limitations of expert systems, and the existing application of expert systems. The knowledge base, the inference mechanism, the context, the explanation facility, the knowledge acquisition facility

and the user interface as components of standard expert system were explained.

OAV, semantic networks, frames, logic programming, rule-based system as knowledge representation modes were discussed with more emphasis on the rule-based system mode. The properties and the components of a production rule were demonstrated. The two types of search strategies (backward chaining and forward chaining) as part of the inference mechanism were briefly discussed. For the rest of the chapter, a detailed review of the existing technologies and applications in the construction field was performed.

1. They are knowledge-intensive programs.
2. They use heuristic in a specific domain of knowledge to improve the efficiency of search.

CHAPTER 5
DEVELOPMENT OF HIGHWAY CONSTRUCTION SCHEDULING ANALYSIS SYSTEM (HWCSAS) MODEL

Introduction

In the construction industry, the need for new customized scheduling techniques for different domains is quite significant for on-time execution of construction projects. These techniques should provide profound analysis and evaluation of construction schedules and the data pertaining to each schedule's activity. In highway construction, the development of a proposed KBES model that evaluates and analyzes construction schedules will motivate the different parties involved to employ scheduling means to control construction projects more efficiently.

The proposed model should evaluate general information of the project such as the planned completion date of the project against the project must finish date, the percentage of critical activities to the total number of activities, the workweek length and the workweek start. The model should also evaluate data pertaining to each activities such as activity's standard description, unit measure, duration, cost, distinctive properties and the interrelation between activities.

The model should advise and report to the user the status of the project as a whole and the status of each activity. If the model encounters any data that violate the knowledge base standards or limits it would report the complexity to the user for subsequent action. The model is to be developed using a standard expert system shell (EXSYS Professional) that will interact with the different dBase files produced by a computerized scheduling software (SURETRAK). To enable a dynamic interaction between the EXSYS Professional and SURETRAK, an SQL language commands will be utilized to retrive the required data form the dbase files generated by SURETRAK program.

Knowledge Acquisition

Three methods were used in collecting information for the knowledge base of the proposed model (HWCSAS). The first involved the analysis of scheduling knowledge in textbooks, literature and technical manuals. This method explored the construction scheduling criticism in general and established the knowledge base for scheduling analysis and evaluation. The method also explored the technical manuals and scheduling instructions produced by the FDOT to regulate highway construction.

The second method of knowledge acquisition is extracting human expertise. This was done by either interviewing experts in highway construction or by exposing them to the knowledge base produced by the first method.

This method is used to obtain a better understanding of the schedule criticism field. The sources of these expertise and the outcomes of these interviews are detailed in Appendix A.

The third method of knowledge acquisition was done by attending and recording expertise during a seminar that hosted FDOT, consultant and contractors construction engineers. The seminar was sponsored by the American Society of Civil Engineering (ASCE) and was held in March, 1992, in Melbourne, Florida. The title and focus of the seminar was "Preparing, Using and Analyzing the Project Schedule." Most of the engineers who attended the seminar were experienced engineers in highway construction with modest background in construction scheduling. The seminar also included a session on using SURETRAK scheduling software on planning and controlling construction project. The seminar justified the choice of SURETRAK for its simplicity and comprehensiveness.

Knowledge Organization

In order to transform the knowledge collected during the knowledge acquisition process to a knowledge base ready to be employed within an expert system, the designated knowledge has to be categorized and structured in a very conclusive way. In this research, the organization of the knowledge collected about highway construction scheduling followed the guidelines used by the U.S. Army Corps of

Engineers Research Laboratory (USACERL) in developing their expert system for evaluating building construction scheduling.

The knowledge-base structure used in the proposed HWCSAS was designed to consist of three types of regulations:

1. General scheduling regulations,
2. General construction regulations, and
3. Highway construction regulations.

The general scheduling regulations assure that the construction schedule complies with standard scheduling practices. These regulations should verify the following:

1. The general requirements of the construction schedule's activities representation such as activities numbers, descriptions and types.
2. The time constraints of the construction schedule such as the reasonability of activities' duration, activities float and the overall completion date.
3. The logic constraints such as activities interrelationships.
4. The cost constraints such as the reasonability of the monetary value assigned to individual activities and the prevention of front-end loading practice.

The general construction regulations should represent expertise that may be applied to a variety of construction projects including highway projects such as the acceptable maximum ratio of (critical/total) activities.

The highway construction regulations are specific to highway projects such as the permits required before commencing the work.

In the following sections, a sample of the knowledge collected during the knowledge acquisition process that will be used to develop the HWCSAS prototype is presented according to the organization structure explained above.

General Scheduling Regulations

General Requirements Regulations

1. Each activity must be coded and has a standard description of the work involved. Codes must be complete, correct, and must reflect the nature of the work. Codes and descriptions should follow the work breakdown structure. Each description should be unique and nonstandard abbreviations should be avoided so any one familiar with the construction work can understand it. Activities should be identified to describe the project in sufficient detail to satisfy the schedule objectives. Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities

durations and costs. Table 5-1 display some highway construction activities and their corresponding code numbers and units.

2. Responsibility centers should be identified for the execution of each activity. These centers may be either individuals or organizational entity.

Time Regulations

1. Durations should be assigned to each activity based on documented previous experience of the organization and other project participants. Durations should also be based on historical performance or quoted data from outside vendors or subcontractors. Durations should also be based on the time of the year the operations are to be executed. In Table 5-2, the production rates of some highway construction activities are displayed.

2. A typical activity duration should be between 1 and 30 calendar days. Long durations activities are difficult to measure. A long duration usually indicates the aggregation of many sub-activities into a more general one. It is difficult to assess progress on this type of activities. An activity with long duration, low

TABLE 5-1. SUGGESTED ACTIVITIES' CODES, UNIT MEASURE AND DESCRIPTIONS

Activity Number	Unit Measure	Description
1000	-	Start
1010	LS	Mobilization
1012	-	Roadway shop drawing preparation and submittal
1014	-	Submission of asphalt pavement mix formula
1016	-	Bridge shop drawing preparation and submittal
1018	-	Submission of concrete mix design
1019	-	Submission of delivery schedule
1020	DA	Maintenance of traffic
1040	ACRE	Erosion maintenance
1100	ACRE	Clearing and grubbing
1200	CY	Truck hauling excavation
1205	CY	Regular excavation
1206	CY	Roadway embankment
1208	CY	Abutment embankment
1600	SY	Stabilization/subgrade
1620	SY	Topsoil
1750	SY	Reseating existing concrete pavement
2200	SY	Base construction
3000	GA	Priming
3270	SY	Milling existing asphalt pavement
3280	CY	Resurfacing
3500	SY	Pavement (asphalt and/or concrete)
3600	CY	Bridge approach slab
4000	CY	Retaining walls
4250	LF	Drainage
4500	LF	Prestressed construction
4550	LF	Test piling
4551	LS	Segmental casting facility mobilization

TABLE 5-1.--Continued.

Activity Number	Unit Measure	Description
4552	LS	Fabrication and Delivery of Piling
4553	LS	Segmental Fabrication
4554	LS	Beam or Girder Fabrication
4555	LF	Pile Installation
4556	CY	Pile Caps or Spread Footings
4557	LF	Columns
4558	EA	Pier caps
4559	EA	End bents
4560	LS	Beam, girder or segment erection
4561	EA	Diaphragms
4562	LS	Deck placement
4563	EA	Parapets
5200	LF	Curb and gutter
5205	SY	Sidewalk
5300	SY	Riprap
5360	LF	Guardrail
5450	SF	Retained earth wall
5460	PM	Rumble strips
5500	LF	Fencing
5600	TN	Painting
5700	SY	Seeding
5750	SY	Sodding
5770	SY	Reworking shoulders
5800	LS	Landscaping
6300	LS	Highway lighting
6500	LS	Signalization
7000	LS	Roadside signing
7060	EA	Reflective pavement markers
7100	LF	Stripping
7360	LS	Utility relocation
9999	-	End of job
99999	-	Project duration

TABLE 5-2. HIGHWAY CONSTRUCTION ACTIVITIES' PRODUCTION RATES.

Activity	Production Rate
TRUCK HAULING EXCAVATION	900 CY/day, when volume less than 100,000 CY, 38,000 CY/day when volume between 100,000 - 300,000 CY, and 7500 CY/day when volume exceed 300,000 CY.
REGULAR EXCAVATION	T = 0.0000367 V + 61 when volume exceeds 300,000 CY, 27,500 CY/day when volume exceeds 1,300,000 CY, productivity rate is.
SHOULDER REWORKING	1 mile/day.
CLEARING AND GRUBBING	Ranges from 1 - 10 acres/day depending on nature but not to exceed 20 days.
STABILIZATION/ SUB-GRADE	500 SY/day but not to exceed 10 days.
BASE CONSTRUCTION	T = 0.000028 V +9.43, when volume less than 260,000 SY, 4500 SY/day, when volume exceeds 260,000 SY is.
MILLING EXIS. ASPHALT PAVMNT.	8000 SY/day but not to exceed 20 days.
ASPHALT PAVEMENT	T = 0.008 V + 5, when volume less than 65,000 tons 1,000 tons/day, when volume exceeds 65,000 tons.
DRAINAGE	100 to 400 LF/day.

TABLE 5-2.--Continued.

Activity	Production Rate
CURB AND GUTTER	400 to 800 LF/day.
PERMANENT BARRIER WALLS	200 LF/day.
SIDEWALK	300 SY/day.
SODDING	500 SY/day, but not to exceed 10 days.
SEEDING	23,500 SY/day, but not to exceed 5 days.
RESURFACING	200 CY/day.
GUARDRAIL	1500 LF/day.
REFLECTIVE PAVMNT MARKERS	500 units/day, when units is less than 5,000 and 1,000 units/day, when units exceeds 5,000.
RESEATING EXISTING CONCRETE PVMNT.	5,000 SY/day.
SIGNALIZATION	15 days/intersection.
HIGHWAY LIGHTING	5 standard/day.
FENCING	500 LF/day, when length is less than 10,000 LF, and 1,200 LF/day, when length is more than 10,000 LF.

SOURCE: FDOT production rates for estimating working days (1989).

value, and float may be regarded as unimportant and therefore allowed to keep its duration.

3. Critical activities should not have durations of more than 20 calendar days, or more than one pay period.

4. The completion date must comply with the contract requirements. The contract specifications define the period within which work must be completed from Notice to Proceed. A schedule consuming more than the specified number of contract days is not acceptable. However, a schedule showing early completion is acceptable but might not be approved by the FDOT, provided acceptable time constraints are placed on governmental activities.

<u>Logic Regulations</u>

1. The schedule shall show the order and the interdependence of activities and the sequence in which the work is to be accomplished as planned by the contractor. Sequencing and interdependencies between these activities must be logical and must reflect the restraints between and among activities. Examples of these interdependence restraints are the following:

a. Clearing and grubbing activity should not start before maintenance of traffic activity had started.

b. Truck hauling excavation activity or regular excavation activity should not start before clearing and grubbing activity had started.

c. Base construction activity should not start before topsoil activity had started.

d. Pavement activity should not start before milling existing asphalt pavement activity had started.

e. Stripping activity can not start before roadside signing has started.

f. Maintenance of traffic activity should not start before Mobilization activity.

g. Erosion maintenance activity can not start before maintenance of traffic activity has started.

h. Drainage work can not start before regular excavation work has started.

i. Stabilization/sub-grade work can not start before clearing and grubbing has started.

j. Regular excavation can not start before clearing and grubbing has started.

k. Drainage work can not start before truck hauling excavation work has started.

l. Curb and gutter work can not start before stabilization/sub-grade has started.

m. Base construction can not start before curb and gutter has started.

n. Sidewalk work can not start before curb and gutter work has started.

o. Priming can not start before base construction has started.

p. Asphalt pavement can not start before priming has started.

q. Stripping activity can not start before asphalt pavement has started.

r. Installing reflective pavement markers can not start before stripping has started.

s. Seeding work can not start before topsoil has started.

t. Sodding work can not start before topsoil has started.

2. Lags on finish-to-start constraints usually suggest date fixing. All lag values must represent time consumed by effort for valid time reserve calculations. To be valid, a lag on a finish-to-start constraint could be replaced with an activity that represents definable

project effort. For example, if there is a submittal log, it should be considered as an activity and should be tied to the schedule.

3. Start-to-start constraints should have lag values representing a portion of the predecessor activity. The absence of a lag value on a start-to-start constraint normally indicates improper modeling of activity overlap. The value of the lag should be less than the predecessor activity's duration.

4. Finish-to-finish constraints should have lag values representing a portion of the successor activity. The absence of a lag value in a finish-to-finish constraint normally indicates improper modeling of activity overlap. The value of the lag should also be less than the successor activity's duration.

<u>Cost Regulations</u>

1. The monetary value of administrative activities, like submittal, should be zero. The cost of preparing submittal is considered part of the overhead and the contractor must distribute costs to other activities.

2. The monetary value of each activity should conform to the range specified in the contract. In addition, the monetary value assigned to each

activity should represent a reasonable amount for that work. This analysis may be based on the cost of similar work completed recently. Examples of the average unit prices for some highway construction activities are shown in Table 5-3.

3. The total monetary value assigned to individual activities must equal the contract amount.
4. Any subcontractor performing 10% or more of the total contract value is considered a major subcontractor, and should participate in the contractor's development plan.

General Construction Regulations

1. The critical path usually consists of relatively few activities of the baseline schedule. If many parallel paths and/or a large number of critical activities exist, it is likely that some durations have been overstated for the purpose of eliminating float. Managing simultaneous critical paths is harder than managing a single one. If the critical path activities rise much above 20% of the project total activities, this mean that the contractor failed to schedule the project adequately. This will make it difficult to manage the project, which, therefore, should be rescheduled. Float

TABLE 5-3. ACTIVITIES' AVERAGED UNIT PRICES.

Activity	Averaged Unit Price
Clearing and grubbing	$4854.11/acre
Truck hauling excavation	$3.73/CY
Regular excavation	$2.78/CY
Roadway embankment	$7.00/CY
Stabilization/subgrade	$1.31/SY
Reseating concrete pavement	$0.28/SY
Base priming	$1.41/GA
Topsoil	$0.42/SY
Base construction	$3.65/SY - $18.00/SY
Resurfacing	$27.69/ton
Milling existing asphalt pavement	$0.47/SY - $1.22/SY
Asphalt pavement	$1.81/SY - $9.30/SY
Approaching concrete slab	$43.32/SF
Curb and gutter	$27,000.00 - $32,485.00/mile
Riprap	$29.66/LF and $73.37/LF
Retaining walls	$11.75/SY and $19.86/SY
Rumple strips	$5.32/LF and $22.30/LF
Permanent barrier walls	$2.13/LF and $8.95/LF
Sidewalk	$0.05/SY
Guardrail	$0.45/SY
Fencing	$1.04/SY and $1.99/SY
Seeding	$3.00/EA and $3.74/EA
Shoulder rework	$273.28/CY
Sodding	$6.11/LF - $26.10/LF
Reflective pavement markers	$33.70/SY - $55.94/SY

SOURCE: FDOT State-Wide Construction Pay Items Unit Prices Averages.

should be diverse to support the assumption that it has not been manipulated. Zero floating a network defeats its fundamental purpose. One must know which activities are critical and which are not to effectively manage the work.

2. Activities with very high float are not recommended. Although the activity's logic may be correct, this implies that the activity has not been integrated to optimize manpower and other resources. It is rare to have an activity so independent from the main flow of the schedule. Float is of more value early in the life of the job than when the job approaches completion because as the job progresses, the remaining risk factors diminish. For a given activity, float increases in value inversely to its quantity because uncontrollable events causing small periods of delay are more likely to happen than those producing longer delays.

3. Subcontractor plans should be an integral part of the construction schedule. Individuals of a particular trade should be able to see a "detailed" description of their tasks with interfaces to the general plan.

Highway Construction Regulations

1. Within 21 calendar days after the contract had been awarded or at the preconstruction conference, which ever is earlier, the FDOT requires from the contractor to submit a work progress schedule for the project. The schedule shall show the various activities of work in sufficient detail to demonstrate that the contractor has a reasonable plan to complete the project on time.
2. Sufficient association shall be conducted and information provided to the FDOT to indicate coordination of activities with utility owners having facilities within the project limits. The schedule shall conform to the utility adjustment schedules included in the contract documents unless changes are mutually agreed upon by the utility company, the contractor and the FDOT.
3. The FDOT district scheduling engineer, with the involvement of the resident engineer, reviews the schedule, and if it meets the contract requirements submits it to the district construction engineer for approval.
4. If the schedule submitted is determined to be inadequate by the FDOT engineer, it will be

returned to the contractor for correction. The contractor will have fifteen calendar days from the date of transmittal to submit a corrected schedule.

5. The FDOT establishes contract time in calendar days for each project based on the type and volume of the work to be performed. In setting the time, the FDOT considers weekends and holidays. Also, the anticipated affect of utility adjustments or relocations on project progress is considered. Under the calendar day concept, everyday that comes along is a chargeable day (unless contract time has been suspended).
6. Federal, State and local environmental permits must be obtained before any work can proceed.
7. External constraints should be considered, including site access, work of other contractors, local climate and environmental conditions, working schedules of local suppliers, contract milestones, etc.
8. If the construction work requires narrowing the existing road or highway with concrete barricades, the length of the narrowed road or highway must not exceed the specified limit in length by the contract. If the construction

work involves more than the specified limit in length, the work must be divided in sections and scheduled in different times.

9. The contractor shall always conduct the work in such manner and in such sequence as to insure the least practicable interference with traffic.

10. Prior to starting the clearing and grubbing operations, the project engineer should check that all permits, property rights, waivers, archaeological clearances and property easements have been obtained and are in order.

11. Before placing base material, the inspector must be sure the subgrade meets the following requirements.

    - Is firm and unyielding.
    - Has passed bearing tests.
    - Meets grade and cross section.
    - Has the required density.

12. Priming the base: The base must be permitted to cure before the prime coat is applied. The moisture content must not exceed 90% of the optimum moisture at the time of priming.

13. Asphalt plant operations should never be started until the weather conditions at the lay-down site are suitable for placing the mix, etc.

Temperature should not be less than 40 F or more than 120 F.

Decision Tree Development

To set the stage for formulating the knowledge base rules for the proposed HWCSAS, a decision tree that delineates the evaluation process is generated. Figures 5-1 to 5-4 portray the three evaluation stages of the construction schedule. In each stage, the proposed model would interact with one of the dbase files produced by the SURETRAK software. Utilizing the data bases and the mathematical formulas stored in the HWCSAS model, the system would evaluate and analyze the schedule data furnished by the different dbase files.

Figure 5-1 explains the evaluation procedure of the schedule general information such as the compliance of the completion date with the contract requirements. Figure 5-2 shows the evaluation procedure of the schedule criticality such as the percentage of critical activities to total activities. Figure 5-3 displays the evaluation of data pertaining to each activity such as duration, unit measure and unit price. Finally, Figure 5-4 demonstrates the evaluation of activities interrelationships such as Finish-to-Start constraints and the logical dependence between activities.

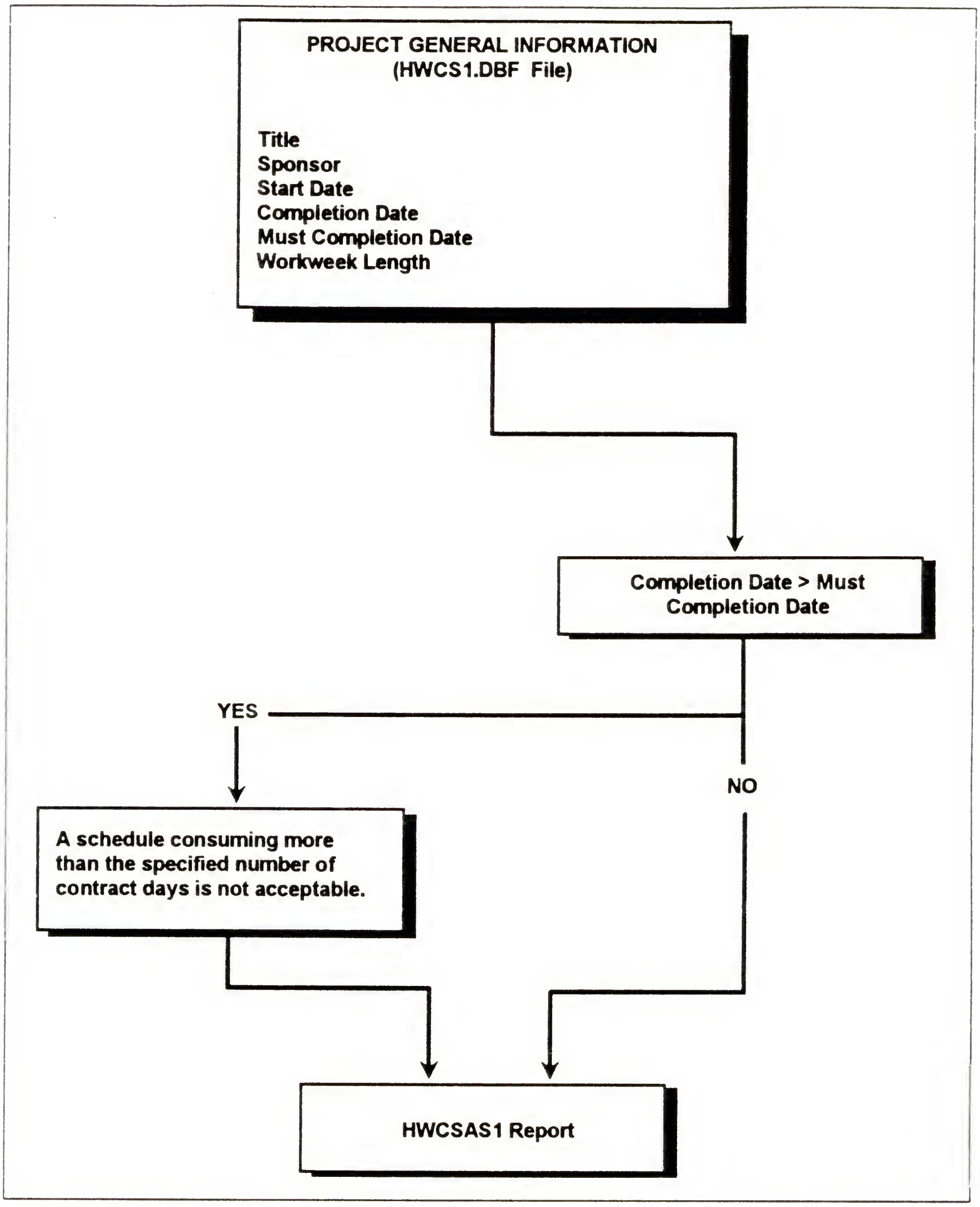


Figure 5-1. Decision tree segment for schedule general information evaluation.

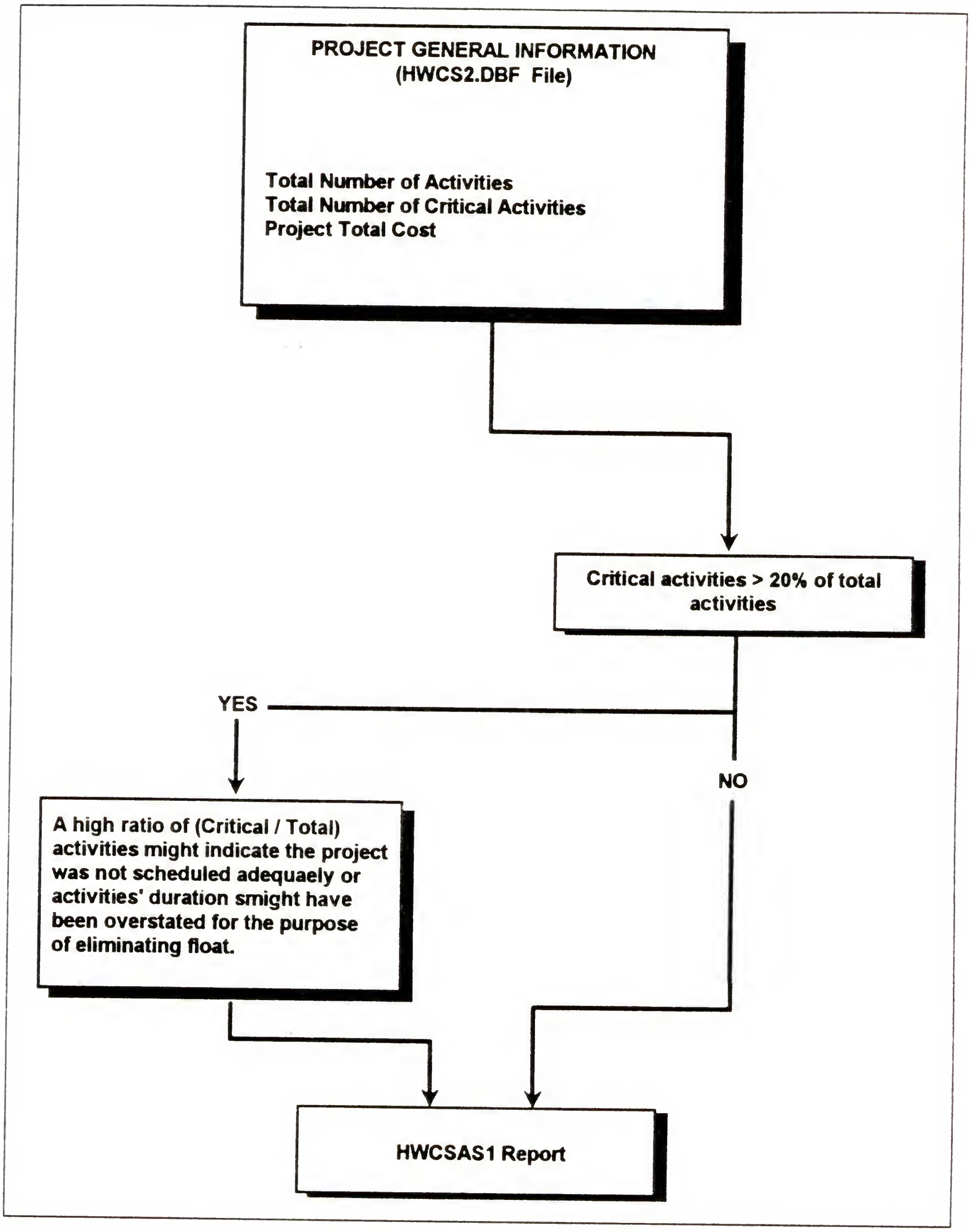
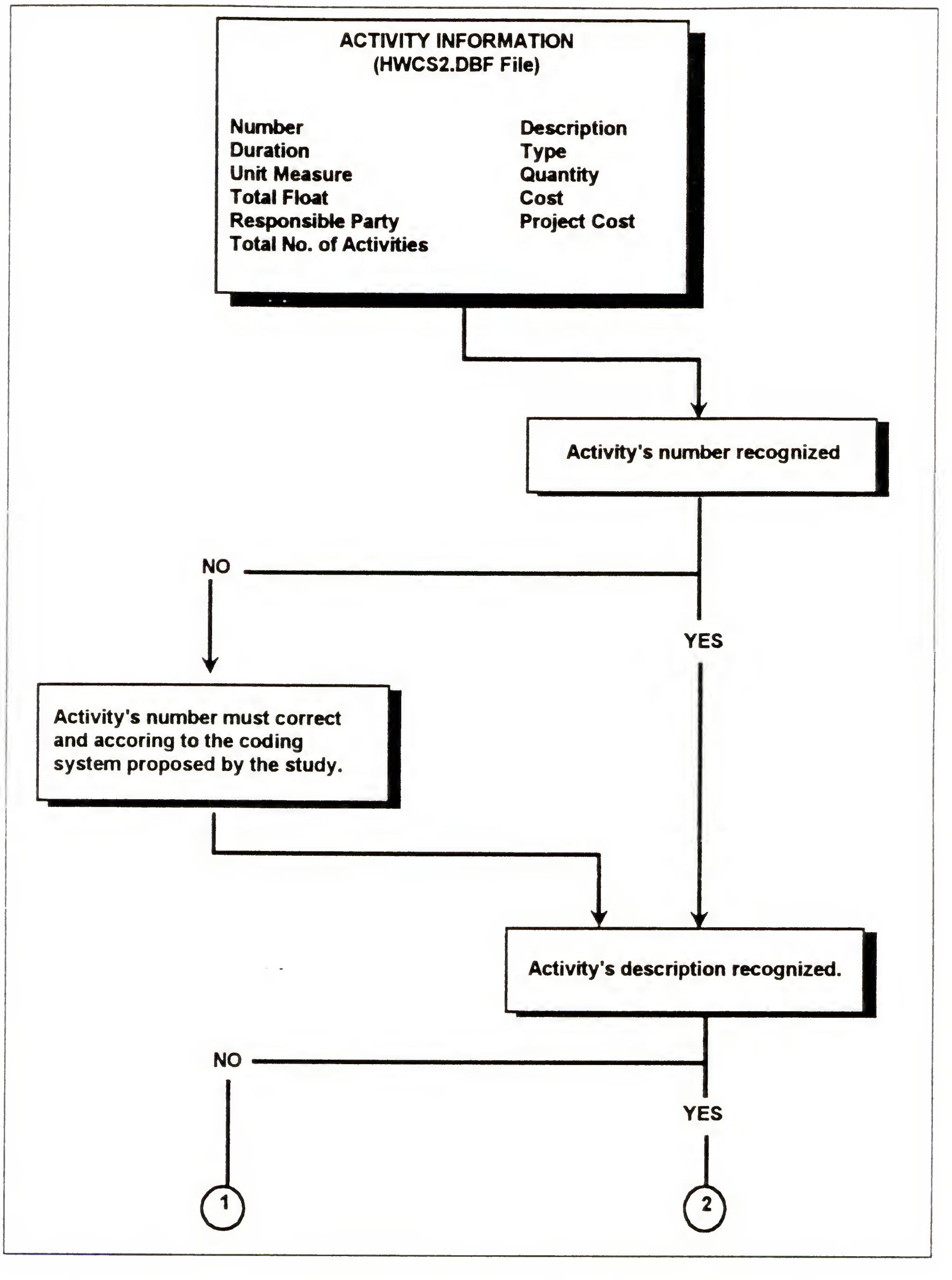


Figure 5-2. Decision tree segment for schedule criticality evaluation.

Figure 5-3. Decision tree segment for activities information evaluation.


ACTIVITY INFORMATION
(HWCS2.DBF File)
Number
Duration
Unit Measure
Total Float
Responsible Party
Total No. of Activities
Description
Type
Quantity
Cost
Project Cost
Activity's number recognized
NO
YES
Activity's number must correct and accoring to the coding system proposed by the study.
Activity's description recognized.
NO
YES
1
2

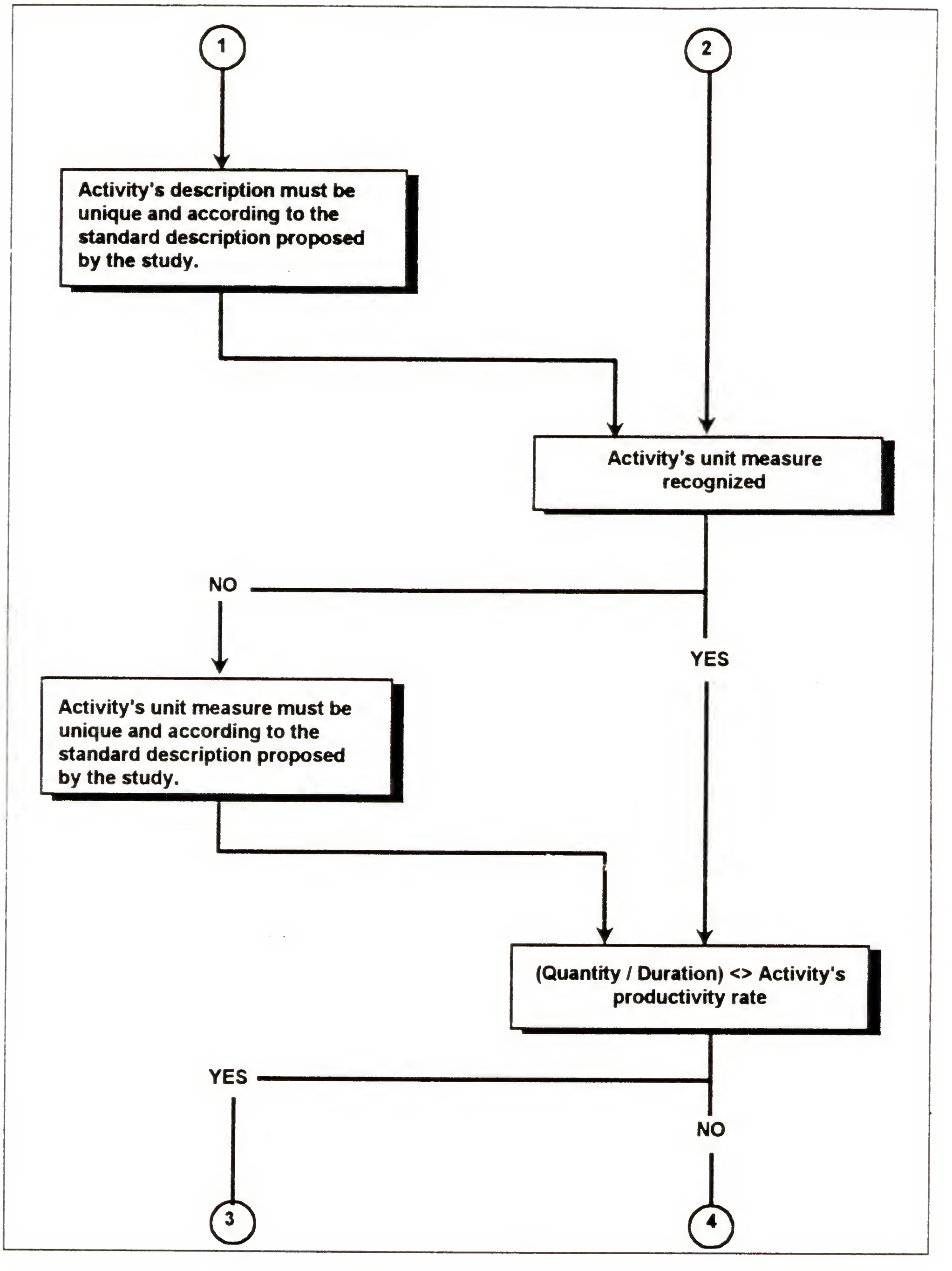


Figure 5-3--Continued.

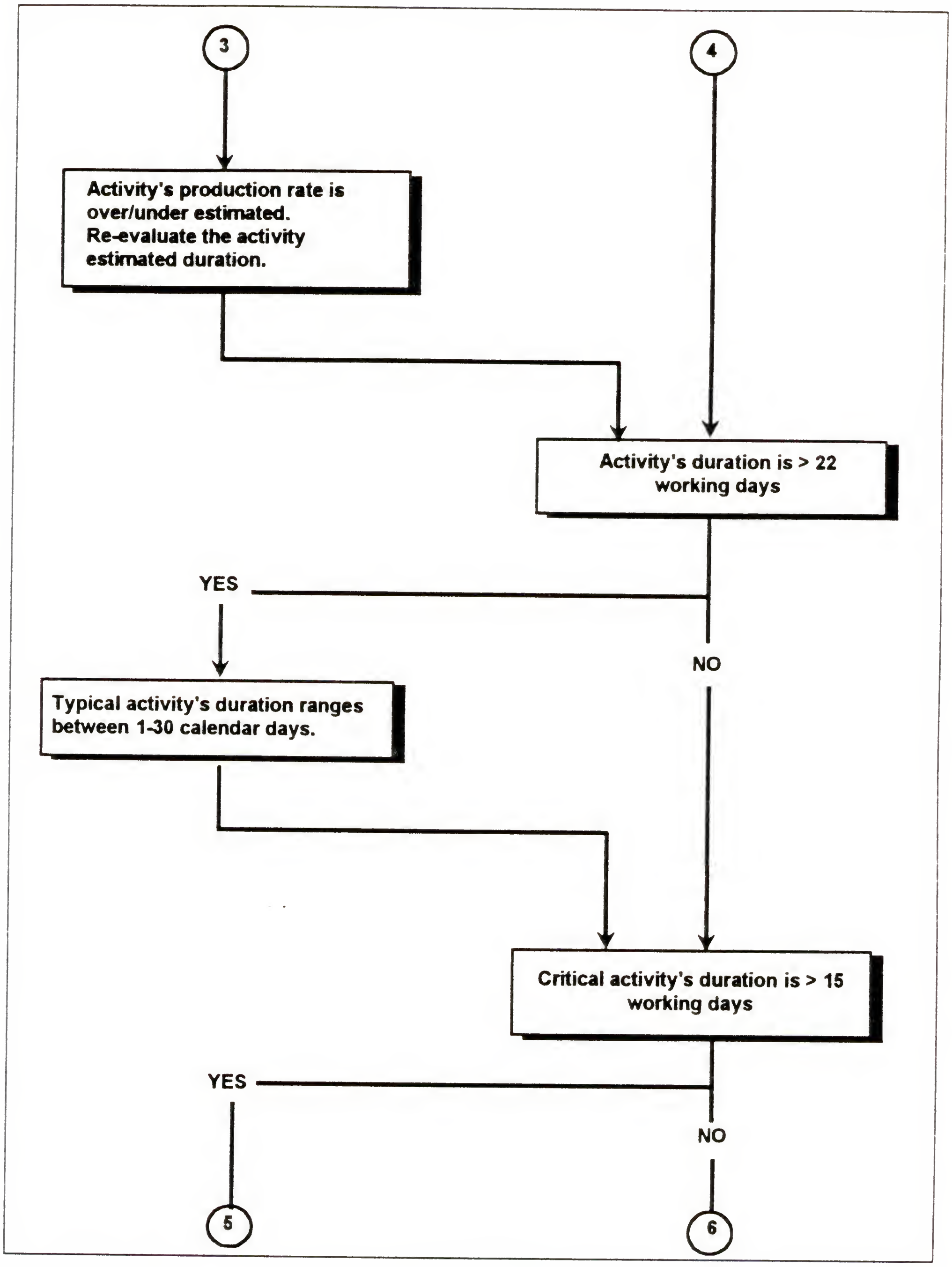


Figure 5-3.--Continued.

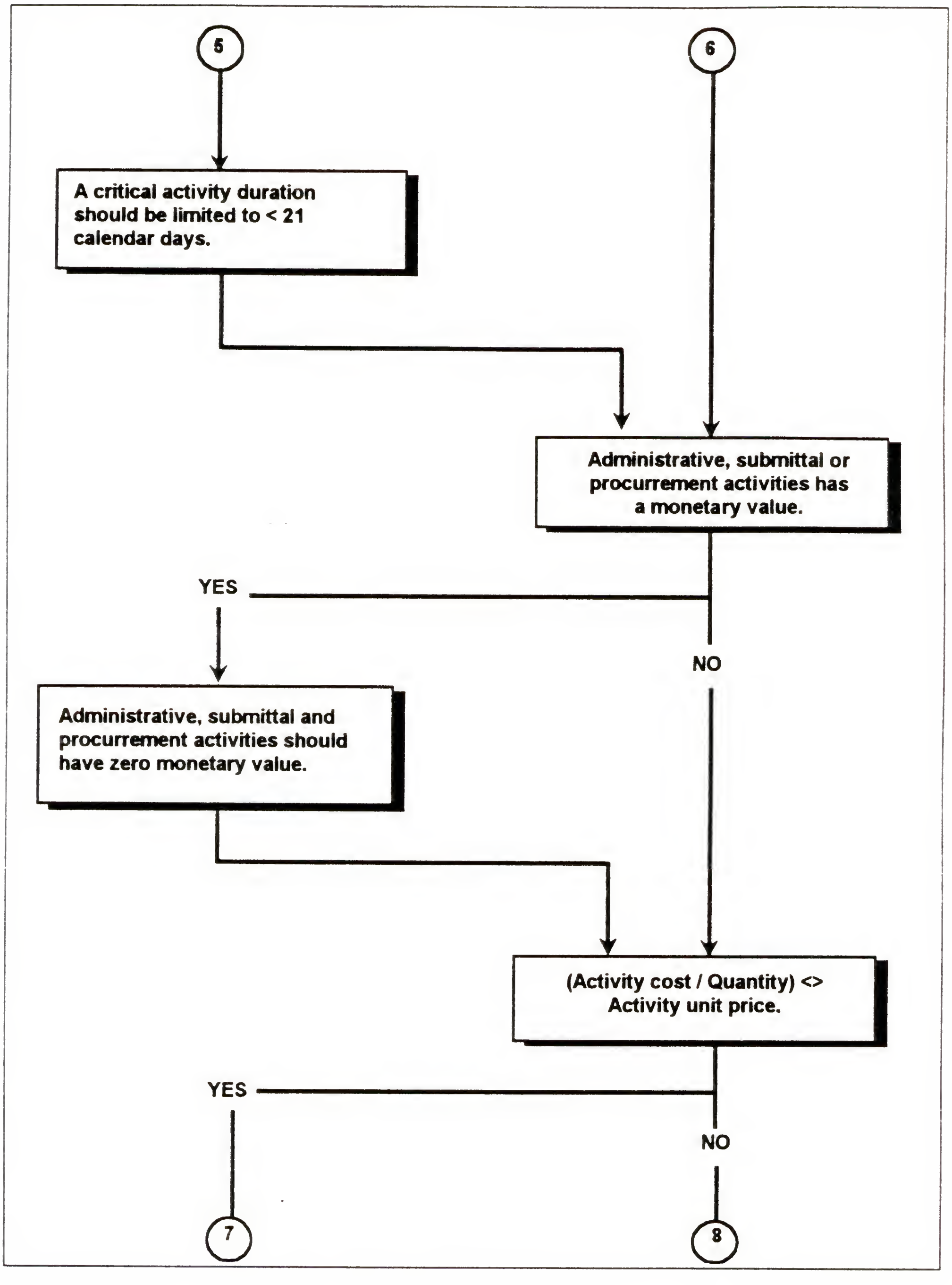


Figure 5-3.--Continued.

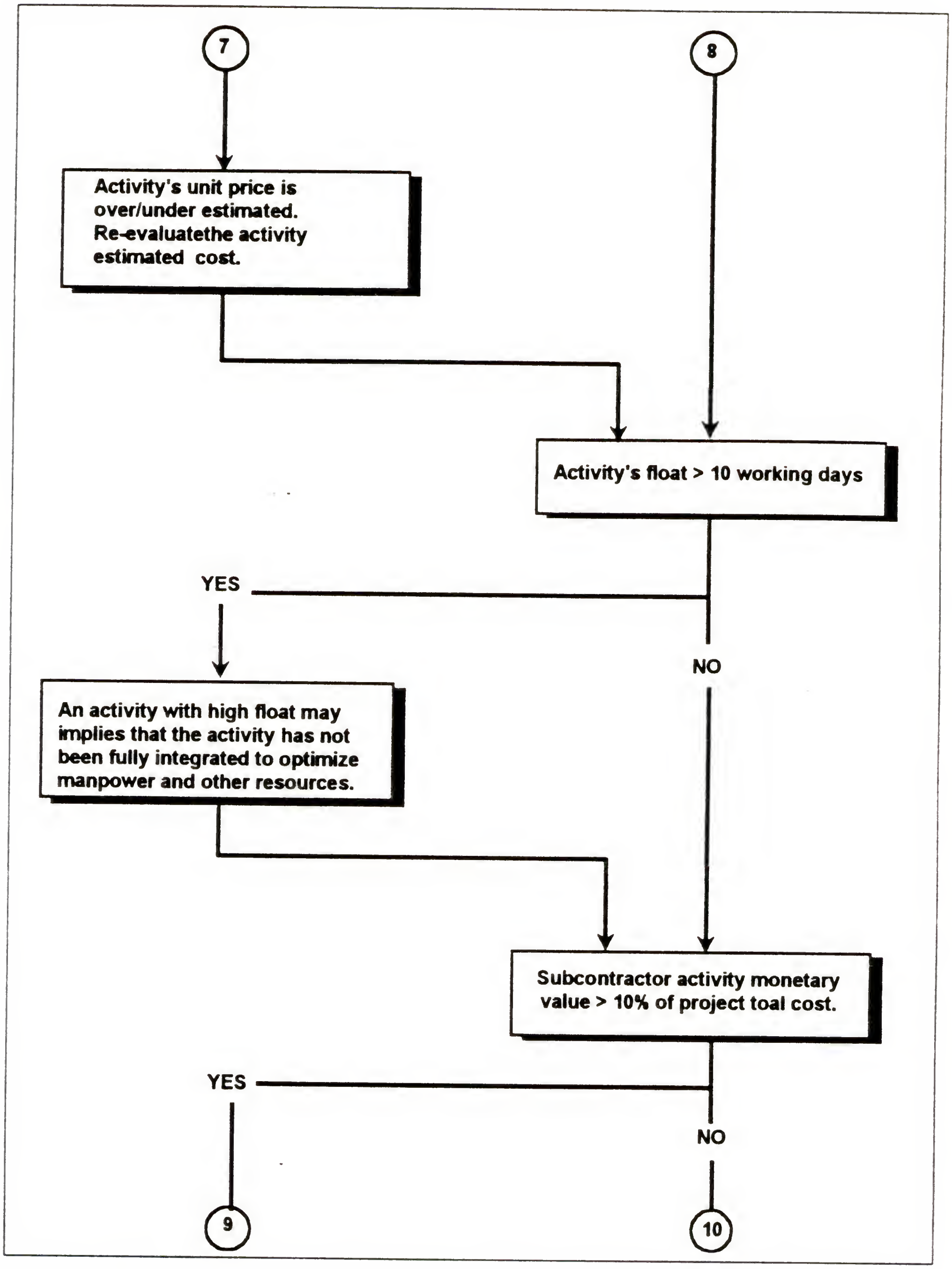


Figure 5-3.--Continued.

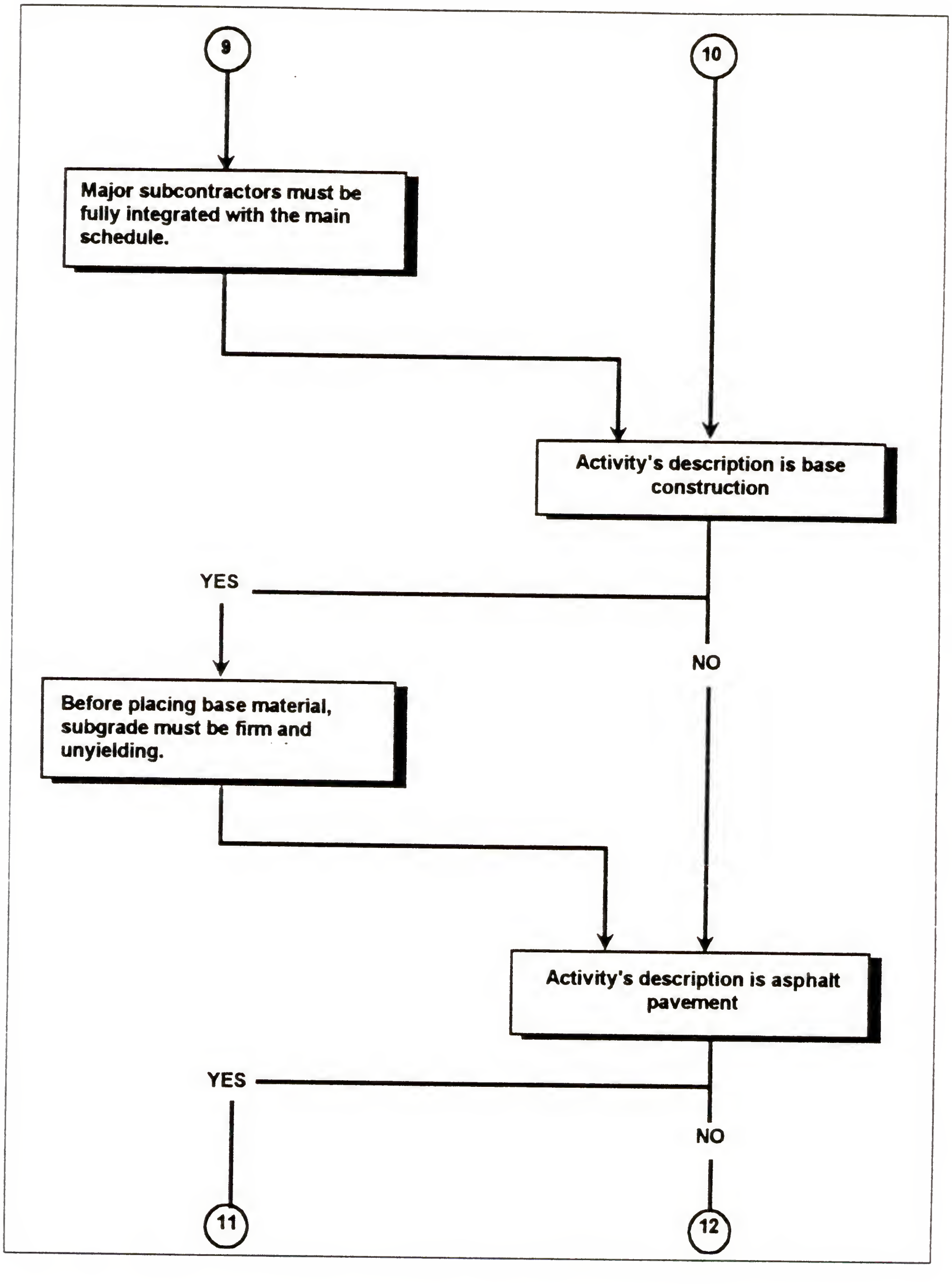


Figure 5-3.--Continued.

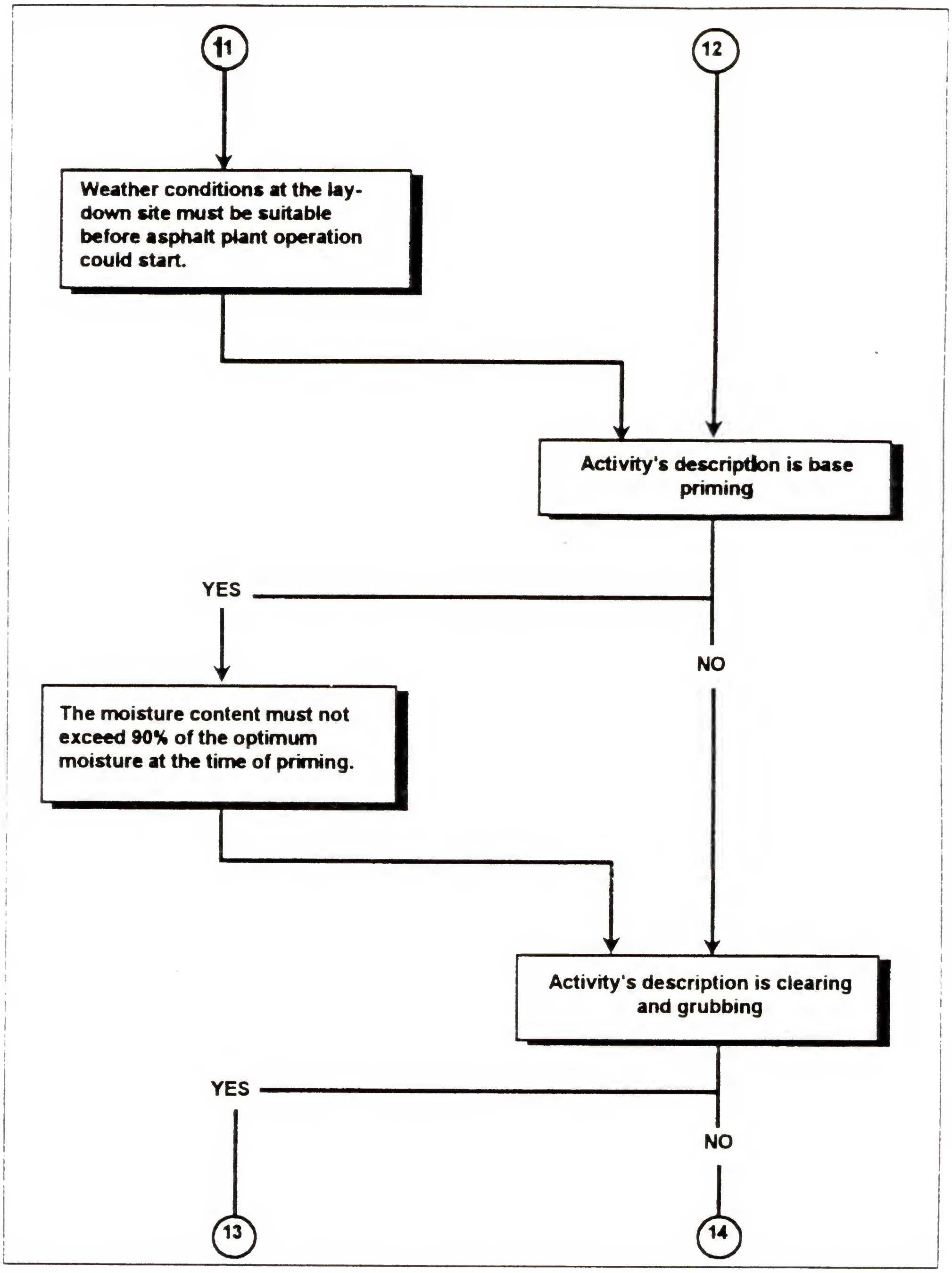


Figure 5-3.--Continued.

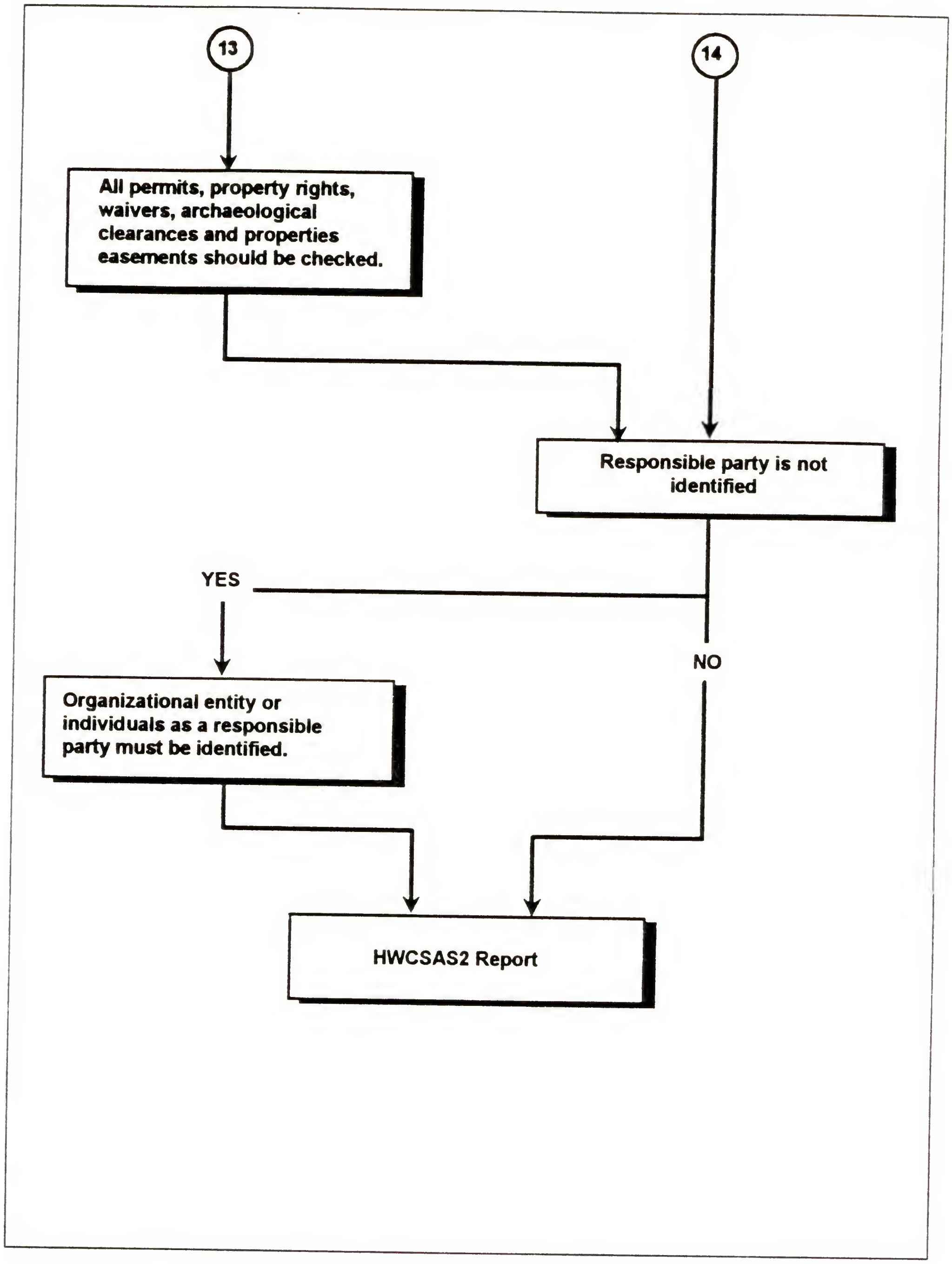
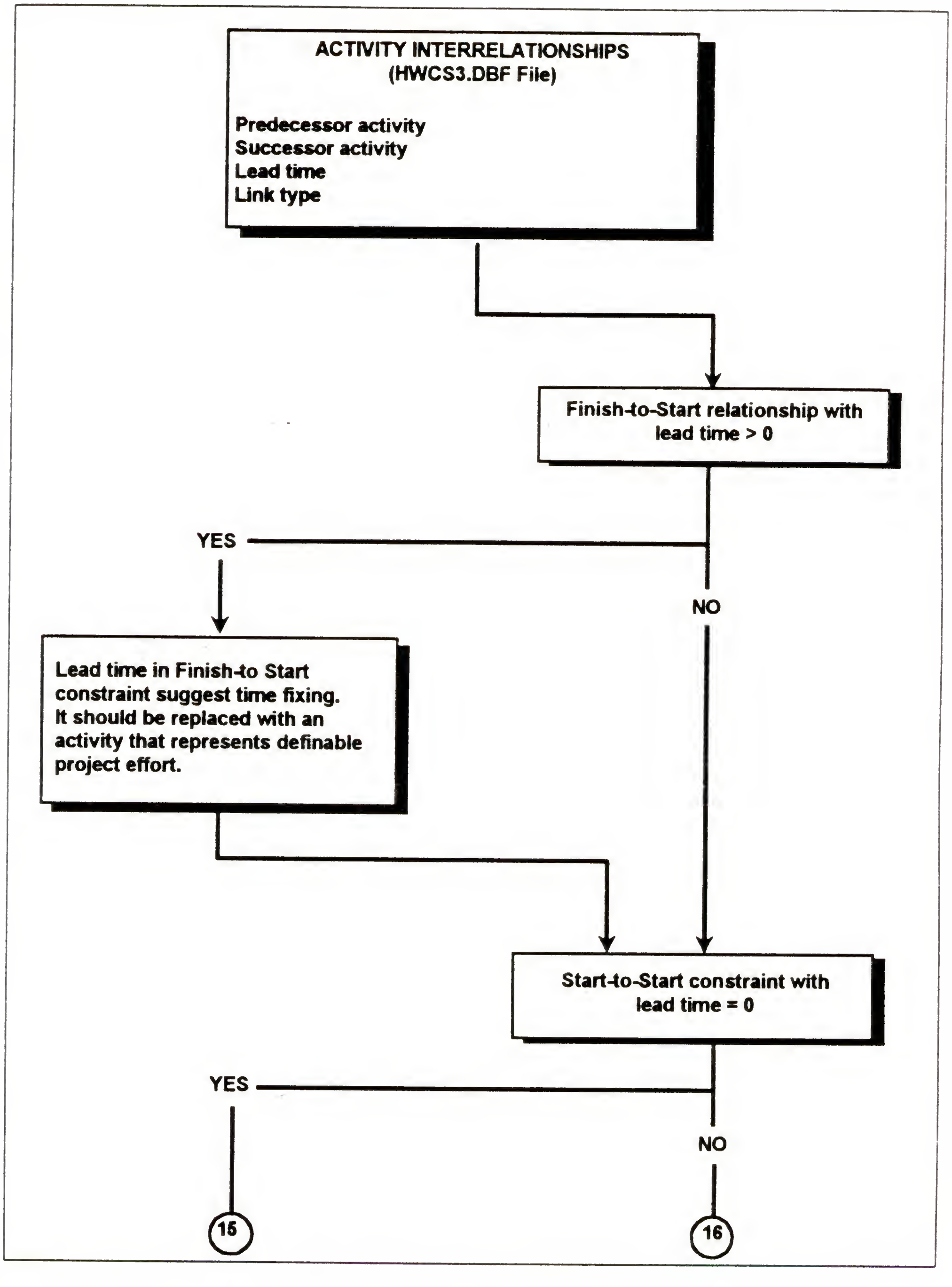


Figure 5-3.--<u>Continued</u>.

Figure 5-4. Decision tree segment for activities interrelationship evaluation.


ACTIVITY INTERRELATIONSHIPS
(HWCS3.DBF File)
Predecessor activity
Successor activity
Lead time
Link type
Finish-to-Start relationship with lead time > 0
YES
NO
Lead time in Finish-to Start constraint suggest time fixing. It should be replaced with an activity that represents definable project effort.
Start-to-Start constraint with lead time = 0
YES
NO
15
16

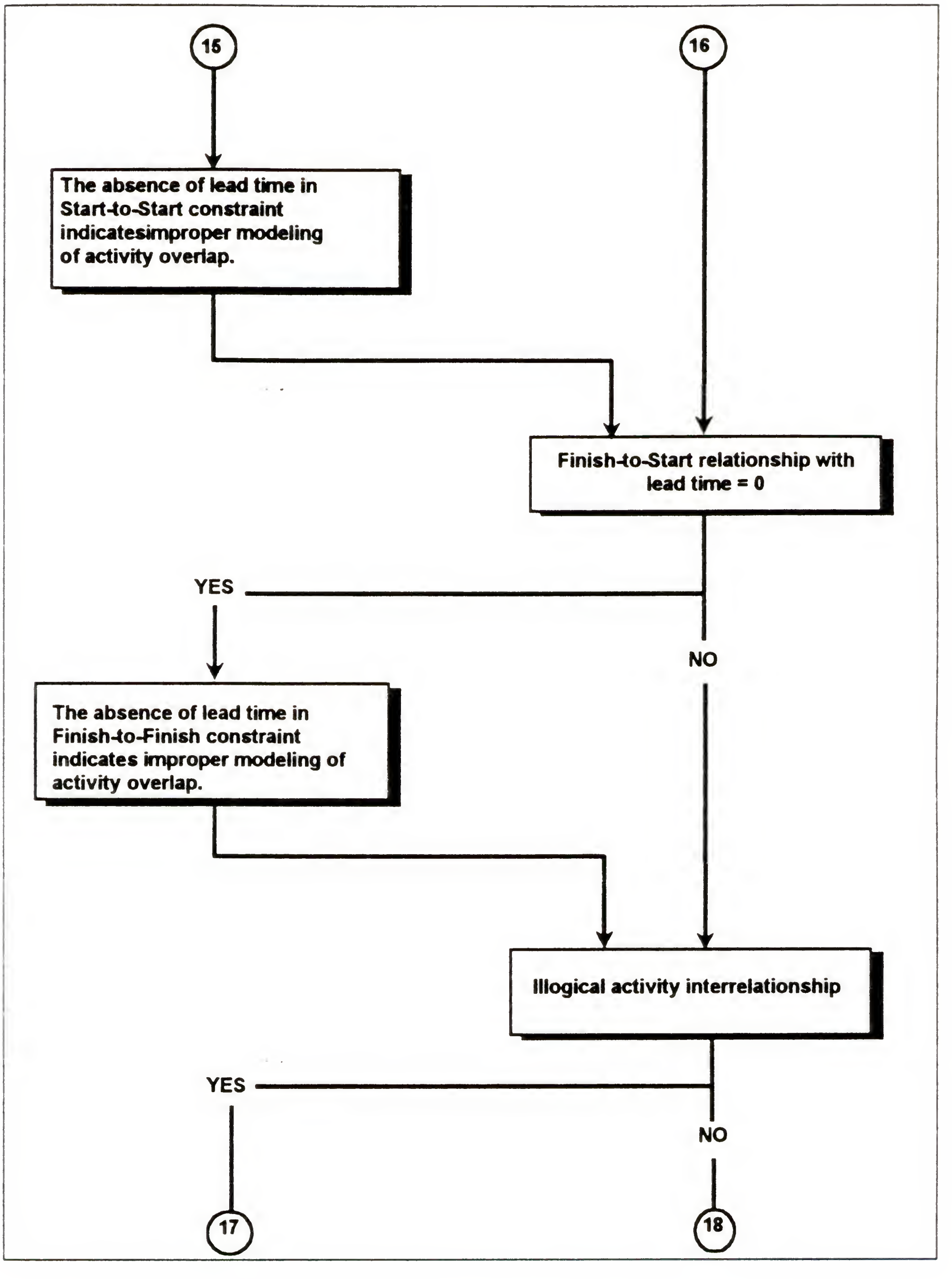


Figure 5-4.--Continued.

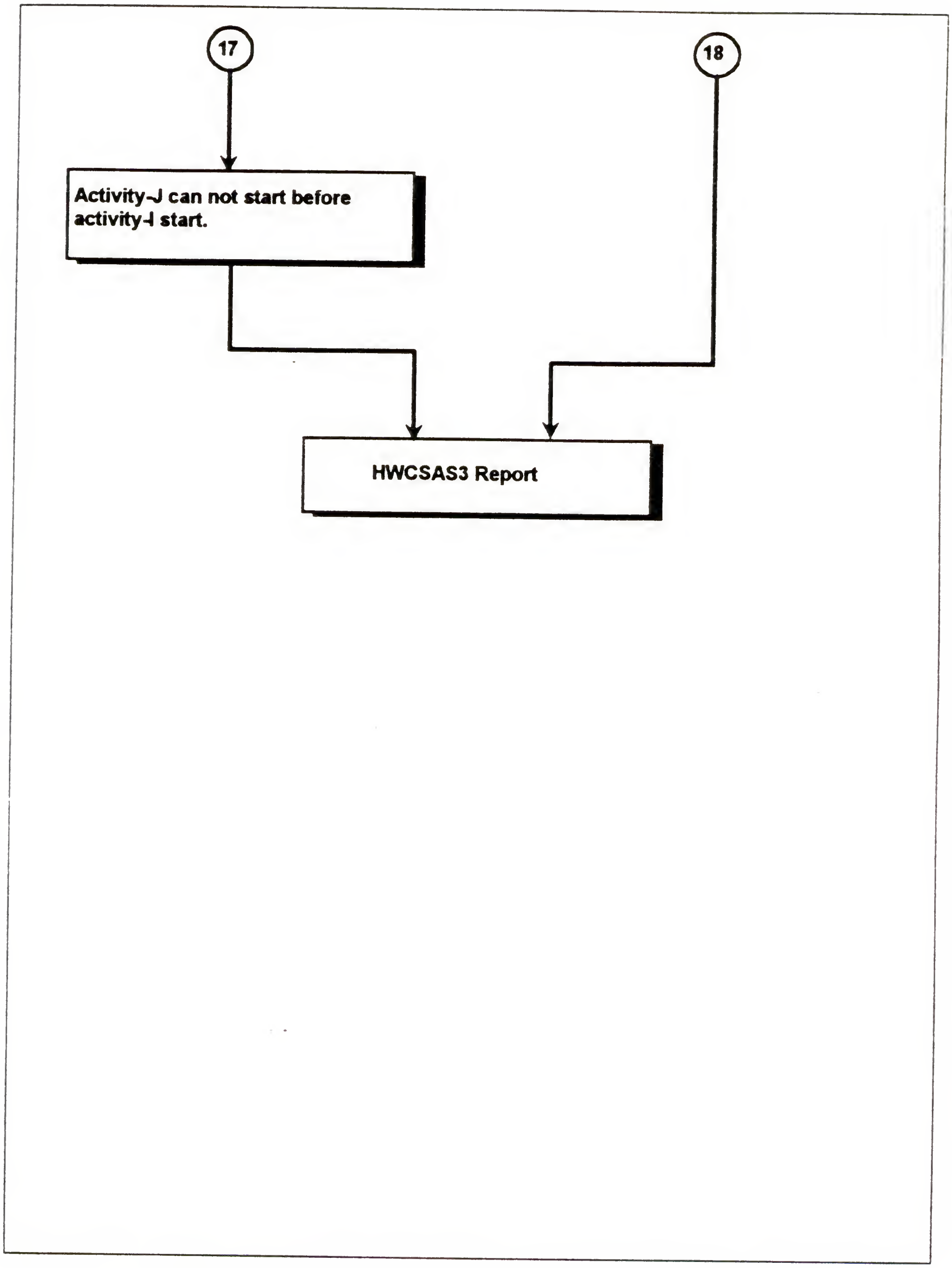


Figure 5-4.--Continued.

EXSYS Professional Expert System Preface

The EXSYS Professional Expert System shell implemented in this study is relatively a sophisticated, flexible and easy-to-use system. It is a type of artificial intelligence program that emulates the interaction a user might have with a human expert to solve a problem. EXSYS Professional programs are written in C language for high speed and efficient utilization of memory. To develop the knowledge base of an expert system, EXSYS Professional uses rule-based system representation (IF-THEN-ELSE production rules). The system can be run by an end user with essentially no training. The developer can customize screens and decide what options are available to the end user.

The principal development tool in EXSYS Professional is the EXSYS Professional Rule Editor. It enables the developer to rapidly generate the expert system knowledge base. When running the rule editor, help screens are available for more detailed information on command options. New rules entered are checked against the existing rules for consistency.

EXSYS Professional also includes a rule compiler that allows the developer to create or edit rules with a word processor and then compile the rules for use with the EXSYS Professional Runtime or Editor. The rule compiler allows other programs to generate EXSYS rules which can be compiled into the EXSYS Professional form. For particularly large or

complex problems, blackboarding can be utilized to divide a problem into smaller expert systems that can communicate through a common data file (a "blackboard").

EXSYS Professional has a built-in report generator. This enables the developer to control what data is output to a screen, disk file or printer. EXSYS Professional also has many ways to access data from other programs. This allows easy integration with other applications. There are built-in commands to access data directly from some programs such as dBase and Lotus 123. To enable EXSYS Professional to access data dynamically from external file, a special command language, Standard Query Language (SQL), should be applied. One limitation of EXSYS Professional current version is the inability to retrieve data from two different dBase files or more simultaneously. This limitation restricts the ability to produce elaborate and elegant expert systems. In Table 5-4, other features that EXSYS Professional possesses are presented.

SURETRAK Project Scheduler Preface

SURETRAK Project Scheduler is a project scheduling software that was developed and improved during the last decade. The last version of SURETRAK Project Scheduler was developed by Primavera System Inc. in 1992. Clarity, comprehensibility, detailed schedule reporting and

TABLE 5-4. FEATURES OF EXSYS PROFESSIONAL EXPERT SYSTEM.

	Feature
1	Support of both forward and backward chaining
2	Automatic menu-driven user prompts
3	Several choices for rule confidence factors
4	Brides to external programs for either data acquisition or external program execution
5	Support numeric, string and text variables
6	Support of various mathematical functions
7	Development of custom screens

SOURCE: Ignizio, (1991).

electronic external accessibility to reports are among the features that SURETRAK Project Scheduler possess.

The scheduling technique that the software implement is the advanced precedence diagramming method. Once a project general information and activities' descriptions, durations and relationships are entered, SURETRAK then calculates a project schedule that includes dates and identifies activities that are critical. SURETRAK is also able to generate more information about the project such as resource allocation, cash-flow pattern, activities' grouping and nonworking days information if the user chooses to utilize.

In reporting, SURETRAK has the ability to convert data from it's working files to reporting files used by other software products. Among the different types of reporting files that SURETRAK files could be converted to is dbase files (DBF file extension), which is the interest of this study. In this case, SURETRAK produce eight reporting files that contain the data generated by the software scheduling calculations. The contents of each file is shown in Table 5-5., while the information contained in each file is shown in Appendix B.

To overcome the EXSYS Professional limitation or inability to evaluate data from different dBase files simultaneously, a modification of two slots used for

TABLE 5-5. THE EIGHT FILES WITH DBF FILE EXTENSION SURETRAK EXPORTS EACH CONTAIN DIFFERENT TYPES OF SCHEDULE INFORMATION.

File No.	Contents
(file)1	One record for general project information
(file)2	One record for each activity
(file)3	One record for each link
(file)4	One record for each resource code
(file)5	One record for each resource assigned to each activity
(file)6	One record for each group code
(file)7	One record for each non-workday or exception
(file)8	One record for each cash-flow pattern

SOURCE: SURETRAK Project Scheduler 2.0 Manual (1992).

entering activity's data was done. The first slot, which is the Group Code 3, was changed to show the unit measure for each activity. The second slot, which is the Work Breakdown Structure (WBS), was changed to show the unit measure quantity for each activity. The modifications will display these data within the second dBase reporting file and it will enable the HWCSAS Prototype the desired analysis and evaluation. Another safeguard to be considered to overcome EXSYS Professional limitations is to load all activities entering slots without leaving any blank slot. A blank slot will cause the system to pause and ask for the missing data and then it will apply the supplied data for the remainder activities.

Rules Formulation

Expert systems deal with knowledge rather than data and the files they use are often referred to as knowledge bases. In order to develop the HWCSAS prototype, the HWCSAS knowledge base has to be structured in the form of production rules or IF-THEN-ELSE rules. As it was explained in Chapter 4, a rule is made up of a list of IF conditions and lists of THEN and ELSE conclusions or statements about the probability of a particular choice being the appropriate solution to the problem. If the computer determines that all IF conditions in a rule are true, it adds the rule's THEN conditions to what it knows to be true. If any of the

IF conditions are false, the ELSE conditions are added to what is known.

For HWCSAS prototype, a confidence value system with a range from 0 to 10 is used. This system can positively select or reject a choice (with a value of 10 or 0) but can also allow intermediate values (1 to 9) to indicate choices that may be appropriate. Due to the systematic analysis and evaluation nature of a schedule's activities, HWCSAS prototype used forward chaining as a search strategy. This means that rules are simply tested in the order that they occur. The prototype also used All Possible Rules mode as a derivation mode. This means that all possible relevant rules that can derive needed information will be invoked. Even if one rule is found to be true, the remaining rules are still tested.

To demonstrate the structure of a production rule, a sample rule from the HWCSAS knowledge base is displayed and explained below.

```
RULE NUMBER:  71  (UNIT PRICE 3270)

     IF:
          [ACTNO]="3270"
              and
          ([ACT COST]/[QUANTITY])<0.47 OR
          ([ACT COST]/QUANTITY])>1.22

     THEN:
          -   The average unit price for Milling
              Existing Asphalt Pavement ranges
              between $0.47/SY and $1.22/SY.
          -   Confidence=10/10
          -   Check the activity cost for the above
              activity.
          -   Confidence=10/10
```

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

In this production rule, the rule name (UNIT PRICE 3270) indicates that this rule is used to verify if the unit price of activity 3270, milling existing asphalt pavement, conforms to the unit price range condoned by the FDOT. In the IF segment of the rule, the mathematical expressions calculate the unit price of milling existing asphalt pavement activity by dividing it's cost by it's quantity. The mathematical expressions also test the calculated unit price against the condoned minimum and the maximum unit price range of the activity.

In the THEN segment of the rule, if the calculated unit price proved to be outside the condoned unit price boundaries, two conclusions or statements will be derived. The first conclusion will state the unit price range of milling existing asphalt pavement. The second conclusion will direct the user to review the projected cost of the activity. The ELSE segment was not used in this rule because it was not necessary. In the NOTE part of the rule, additional information about an activity unit price range conformity is supplied. Building up the HWCSAS prototype according to the proposed decision tree required 110 production rules. These rules are classified into three categories. The first category rules deal with diagnosing

and evaluating the schedule general information. An example of these rules is the confirmation that the schedule's completion date satisfies the contract completion date. The second category of rules deal with analyzing the data pertaining to each schedule's activity. Examples of these rules are the verification of activities' numbers, descriptions and units. The third category of rules deal with activities' interrelationships such as the logical order of executing construction activities. In Appendix C, the production rules produced for HWCSAS prototypes are listed.

External Program Interface

To enable HWCSAS to interface dynamically with dBase files produced by external programs, in this case SURETRAK Project Scheduler, a special version of EXSYS Professional equipped with a Standard Query Language (SQL) option has to be used. The SQL interface command file has the ability to connect EXSYS Professional with a specified dBase file and allows it to retrieve multiple records of multiple fields from a dBase file simultaneously. The command file would also specify which rules are to be executed with the data retrieved from that dBase file.

The SQL command file furnishes the feature of calculating aggregate functions such as averages, counts, and maximum and minimum values of different field. Other SQL files may also be employed to design reports' structures

produced by EXSYS Professional during the evaluation session. To develop the HWCSAS prototype, five SQL command files are produced. The first SQL file (HWCSAS.CMD) is used to interface with SURETRAK dBase files, retrieve required data, calculate aggregate functions and execute specific rules with specific data. The second SQL file (HWCSAS.CFG) is used to generate a tracing file of the evaluation session to detect any system malfunctions. The last three SQL files (HWCSAS1A.OUT, HWCSAS1.OUT and HWCSAS2.OUT) are used to customize the reports generated by HWCSAS prototype. A list of these SQL command files is presented in Appendix C. One of the difficulties encountered during the development of the HWCSAS prototype was the inability of the available EXSYS Professional version to retrieve data from two different dBase files or more simultaneously for evaluation purposes. This difficulty limited the ability of the HWCSAS prototype from conducting further elaborate evaluations and analysis.

Summary

The process of developing HWCSAS and its prototype involved many stages. The first stage was to compile facts and extract experiences of highway construction scheduling from the different sources proposed by the study. The second stage was to organize the knowledge base produced by the first stage in a fashion suitable for expert systems environment. For HWCSAS prototype, the knowledge base was

categorized into three types: General Scheduling Regulations, General Construction Regulations and Highway Construction Regulations. The third stage was to construct the decision tree that delineates the evaluation and the analysis process of highways construction schedules. The final stage is to produce the HWCSAS prototype. This stage involves the identification of variables used by the system, the formulation of rules and the development of the special command files that interface the systems with the report files produced by the scheduling software.

CHAPTER 6
PROTOTYPE VALIDATION AND TESTING

Introduction

To validate the developed HWCSAS prototype, two case studies were tested and analyzed. The first case study represented a simple road construction project while the second represented a simple road maintenance project. The data pertaining to each case study were selected from FDOT sample projects. Some efforts were done to customize the data according to the HWCSAS system. Information about each project was first processed through the SURETRAK software to produce eight dBase reports. Then, data generated in the first three dBase reports were evaluated and analyzed by the HWCSAS Prototype. The evaluation results for each project were then displayed by three report files during the evaluation run of each project. According to the evaluation results, the project original information can be modified and updated. A second run by HWCSAS would be performed after producing the modified eight dBase reports to make sure that all schedule critiques had been contained and corrected. For the rest of this chapter, a display of each project original information and a discussion of each project analysis and evaluation by HWCSAS is presented.

Case Study 1

The project data for this case study was produced from a sample project prepared by the FDOT. The project has 17 task activities and 1 hammock activity (project duration). The hammock activity was created to calculate and display the project duration, within the second dBase report file produced by SURETRAK, to overcome the expert system software limitations discussed in Chapter 5. The third group code field and the WBS code field were assigned activity's unit measure and quantity information respectively for the same reason.

Project Initial Data

PROJECT TITLE: FLORIDA HIGHWAY CONSTRUCTION PROJECT # 1
SPONSOR: UNIVERSITY OF FLORIDA
START DATE: 2/28/94
MUST FINISH DATE: 4/01/94

ACTIVITY #	DESCRIPTION	DURATION	TYPE	RESP	SUB #
1000	START	0	ACT	NONE	
1010	MOBILIZATION	2	ACT	MAIN	
1020-10	MAINT. OF TRAFFIC	11	ACT	MAIN	
1040	EROSION MAINTENANCE	8	ACT	MAIN	
1100	CLEARING AND GRUBBING	1	ACT	MAIN	
1205	REGULAR EXCAVATION	3	ACT	MAIN	
1600	STABILIZ. /SUB-GRADE	1	ACT	MAIN	
2200	BASE CONSTRUCTION	4	ACT	MAIN	
3000	PRIMING	2	ACT	MAIN	
3270	MILLING EXIS. PAVMNT	2	ACT	MAIN	
3500	PAVEMENT	2	ACT	MAIN	
5200	CURB AND GUTTER	4	ACT	SUB	3
5205	SIDEWALK	1	ACT	SUB	1
5700	SEEDING	1	ACT	SUB	2
5750	SODDING	1	ACT	SUB	2
7060	REFLECTIVE MARKERS	1	ACT	SUB	5
7100	STRIPPING	1	ACT	SUB	4
7360	UTILITY RELOCATION	5	ACT	SUB	10
9999	END OF JOB	0	ACT	NONE	
99999	PROJECT DURATION	13	HAM	NONE	

ACTIVITY #	DESCRIPTION	UNIT	QUANTITY	COST
1000	START	NONE	0	$0.00
1010	MOBILIZATION	LS	1	$5000.00
1020-10	MAINT. OF TRAFFIC	LS	1	$250.00
1040	EROSION MAINTENANCE	ACRE	5	$5000.00
1100	CLEARING AND GRUBBING	ACRE	5	$25000.00
1205	REGULAR EXCAVATION	CY	8000	$20000.00
1600	STABILIZ./SUB-GRADE	SY	600	$800.00
2200	BASE CONSTRUCTION	SY	3000	$30000.00
3000	PRIMING	GA	1200	$1200.00
3270	MILLING EXIS. PAVMNT	SY	20000	$20000.00
3500	PAVEMENT	SY	20000	$20000.00
5200	CURB AND GUTTER	LF	24000	$24000.00
5205	SIDEWALK	LF	500	$10000.00
5700	SEEDING	SY	24200	$1500.00
5750	SODDING	SY	600	$1200.00
7060	REFLECTIVE MARKERS	EA	500	$2000.00
7100	STRIPPING	LF	20000	$6000.00
7360	UTILITY RELOCATION	LS	1	$10000.00
9999	END OF JOB	NONE	0	$0.00
99999	PROJECT DURATION	NONE	0	$0.00

Analysis and Evaluation Results

The first three files of the eight dBase report files produced by SURETRAK and the three evaluation reports generated by HWCSAS Prototype for this case study are tabulated and listed in Appendix D. In the first HWCSAS report, the prototype evaluation indicated that the ratio of (critical/total) activities surpassed 20%, which according to the HWCSAS knowledge base may mean that the project was not scheduled adequately or some activities durations were overstated. In the second HWCSAS report, the analysis identified 12 activities that had either off-average unit prices or productivity rates. It also found out one activity with nonstandard description and two activities with incorrect unit measure. The analysis

acquainted the user (project manager) with FDOT's specifications to be fullfilled before five activities can be executed. The analysis also identified one sub-contracted activity with a cost exceeded 10% of the project total cost. In the third HWCSAS report, the analysis found no discrepancy in activities' interrelationships. Detailed analysis and recommendations are presented in Appendix D for further study.

Case Study 2

The project data for case study 2 was also produced from a sample project prepared by the FDOT. The project has seven task activities and one hammock activity (project duration). The addition of the hammock activity, and the use of the group code and the WBS code field were also performed for the reasons stated in the first case study.

Project Initial Data

PROJECT TITLE: FLORIDA HIGHWAY MAINTENANCE PROJECT # 2
SPONSOR: UNIVERSITY OF FLORIDA
START DATE: 3/17/94
MUST FINISH DATE: 4/07/94

ACTIVITY #	DESCRIPTION	DURATION	TYPE	RESP	SUB #
1000	START	0	ACT	NONE	
1010	MOBILIZATION	3	ACT	MAIN	
1020-10	MAINT. OF TRAFFIC	7	ACT	MAIN	
3000	PRIMING	2	ACT	MAIN	
3270	MILLING EXIS. PAVMNT.	2	ACT	MAIN	
3500	PAVEMENT	2	ACT	MAIN	
7060	REFLECTIVE MARKERS	1	ACT	SUB	1
7100	STRIPPING	1	ACT	SUB	1
9999	END OF JOB	0	ACT	NONE	
99999	PROJECT DURATION	9	HAM	NONE	

ACTIVITY #	DESCRIPTION	UNIT	QUANTITY	COST
1000	START	-	0	$0.00
1010	MOBILIZATION	LS	1	$3,000.00
1020-10	MAINT. OF TRAFFIC	DA	1	$250.00
3000	PRIMING	GA	1000	$1,000.00
3270	MILLING EXIST. PAVMNT	SY	18000	$20,000.00
3500	PAVEMENT	SY	18000	$18,000.00
7060	REFLECTIVE MARKERS	EA	300	$1,200.00
7100	STRIPPING	LF	10000	$3,000.00
9999	END OF JOB	-	0	$0.00
99999	PROJECT DURATION	-	0	$0.00

Analysis and Evaluation Results

In the first HWCSAS report, the prototype evaluation again indicated that the ratio of (critical/total) activities surpassed 20%. In the second HWCSAS report, the analysis identified three activities that had either off-average unit prices or productivity rates, and one activity with nonstandard description. The analysis also acquainted the user with FDOT's specifications to be fulfilled before two activities can be started. As in the first case study, the analysis in the third HWCSAS report found no discrepancy in activities' interrelationships.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

Summary and Conclusions

Project scheduling has been an important aspect of the construction industry for many decades. The use of existing computerized scheduling software has introduced a powerful management tool to control and deliver on-time projects. The increase in contracts' annual volume, time value, projects complexity and administrative regulations is commanding the need for more coaching, and analytical and distinct computerized scheduling techniques for each construction domain.

Among the three basic types of scheduling techniques: time scheduling, network scheduling and probabilistic network scheduling; network scheduling or the CPM is considered the most practical and effective technique because of its relative clarity, flexibility and comprehensiveness. A computerized version of network scheduling technique supplied the user with an abundant amount of information including activities interrelationships, time boundaries, costs and resources.

In the field of highway construction, the employment of computerized scheduling techniques has been limited to

the preparation of the initial schedule and the estimation of the project duration. One main reason for the limited implementation of is the software inflexibility and inadoptability. Another reason is that the FDOT does not have an activity-oriented coding system, instead, it only uses a pay-item coding system for compensating contractors for their work. Due to these reasons, the advantages of utilizing the information produced by these software for monitoring and controlling these projects is not fully realized.

The objective of this study was to develop a discrete diagnostic system called HighWay Construction Scheduling Analysis System (HWCSAS). The system examines the information generated by an available computerized scheduling technique and provides the user with qualitative, subjective and analytical information regarding highway construction schedules. The system also furnishes the highway construction parties with administrative instructions regarding the executions of different highway construction activities. The development of HWCSAS mandates the utilization of a KBES approach. This approach involves the use of an available microcomputer-based expert system shell in conjunction with available commercial project scheduling software.

The first step in developing HWCSAS is to acquire the knowledge required for the system knowledge base. The knowledge base was accumulated by using three methods:

1. Reviewing literatures pertaining to the procedures and the analysis techniques of schedules preparation and monitoring.
2. Reviewing FDOT manuals and technical reports relating to highway projects scheduling's specifications and regulations.
3. Interviewing and extracting expertise from highway construction experts.

The process of the knowledge acquisition has resulted in three main types of knowledge; general scheduling regulations, general construction regulations, and distinct highway construction regulations.

The second step of developing HWCSAS is to construct a decision tree that represents the diagnostic procedure of analyzing and evaluating construction schedules. After the construction of the HWCSAS decision tree, the formulation of rules, data bases, interfacing commands with external programs and method of reporting is done using the expert system shell, EXSYS Professional.

The third step of HWCSAS development is to validate the system by testing the produced prototype using some highway construction schedules. Two initial construction schedules, construction project schedule and maintenance

project schedule were tested. The results of each test provided a variety of critiques regarding observed malfunctions about schedule activities.

In conclusion, the development of the HWCSAS and its knowledge base would be a suitable answer for prompting the highway construction industry in implementing computerized scheduling techniques into managing and controlling construction projects. By developing a complete activity oriented coding system, perfecting and elaborating the existing HWCSAS knowledge base, and by facilitating the system to do in-progress schedule evaluation, HWCSAS would serve as a powerful tool for evaluating and analyzing highway construction schedules. Since an elaborate knowledge base for evaluating all types of highway construction projects would become very large, it would be more practical to produce specialized HWCSAS versions for the different types of highway construction projects.

It is expected that the near future will witness a new generation of project scheduling software. The amalgamation of both conventional and artificial intelligence programming would be the base for specialized scheduling software for the different types of construction domains.

Recommendations

In-Progress Schedule Analysis

The developed HWCSAS prototype is limited in it evaluation and analysis to initial highway construction

schedules. The reason that prevented HWCSAS prototype from conducting in-progress highway construction schedules evaluation is the inability of EXSYS Professional expert system to retrieve data concurrently from two or more dBase files that are generated by SURETRAK Project Scheduler. With the progressive advancement on expert system technology, the elimination of this difficulty is expected. In fact, during the course of this research, the ability to interface with external programs dynamically was mastered only through the latest version of EXSYS Professional that is equipped with (SQL) language option. Once the mentioned inability is overcommed, HWCSAS prototype should be easily modified and to evaluate in-progress schedule.

Elaborate HWCSAS Prototype

The developed HWCSAS prototype is also limited in its evaluation and analysis of the construction schedule. Due to time constraint, a confined portion of the generated knowledge base was applied in building up this prototype. A comprehensive HWCSAS prototype, once it is developed, should provide highway construction parties with vast evaluations and instructions in regard with the construction schedule and the execution of its activities. Such system should be able, for example, to preform the following functions:

1. Evaluate resources consumptions and its rate of consumption.

2. Analyze the cash-flow patterns and advise the user of expected future financial inconveniences.
3. Identify responsibility centers for each activity and provide them with instructions and specifications regarding the ideal execution of that activity.
4. Perform in-progress and delay analysis
5. Analyze float consumption rate and predict expected delays.
6. Detect Front-end loading practice.
7. Advise the user with the best schedule acceleration procedure.

APPENDIX A
INTERVIEWED HIGHWAY CONSTRUCTION SCHEDULING EXPERTS AND GENERATED KNOWLEDGE

Interviewed Highway Construction Scheduling Experts

I. Department Of Transportation FDOT officials:

1. Florida State Scheduling Engineer, Mr. John Shriner.

2. Florida District 2 Scheduling Engineer, Mr. Ananth Parsad.

3. Ocala Construction Office Resident Engineer, Mr. Richard Newsome.

4. Gainesville Construction Office Project Manager, Mr. Jamal Hasona.

II. Highway Construction Management Consultant:

5. Post Buckley, Schuh & Jernigan, Inc. Program Manager, Mr. Del Younker.

III. Highway Construction Contractor:

6. Hubbard Construction Co. Project Scheduling Coordinator, Ms. Carla Alford.

Generated Knowledge

1. FDOT State Scheduling Engineer, (Mr. Jhon Shriner):

   a. If there is a submittal log, submittal should be tied to the schedule and approval time should be shown.

   b. The contractor usually possesses the means and the methods that control the schedule progress, and he is the one who decide how to schedule the work required from him, within the contract specifications.

   c. The project scheduler will be able to list the activities required for each phase of the project only after building the project network.

   d. There is no one-to-one correlation between pay-items and activities.

   e. The FDOT should be entitled to float ownership and should be able to use float to accommodate changes to the project.

f. A dollar value may be assigned to owner controlled activities such as Design Approval.

g. Water Management permit might be required for some highway construction contracts.

h. The maximum moisture content allowed in the base before priming depend on the type of the material used for the base.

i. Weather temperature limits for asphalt pavement varies and should not be limited between 40 F and 120 F.

j. The percentage of critical activities to the total number of activities does not have to be limited to 20%.

k. It is not rare to have an activity so independent from the main flow of the schedule.

l. An initial schedule showing early completion than the contract completion date is not acceptable.

m. The practice of front-end-loading is legal in FDOT contracts.

n. Depending on the contract language, retainage on payment request for labor intensive activities may be applicable.

o. In highway construction, the rule of thumb saying "by the time the project is 33% and 66% complete, the contract may have recovered 25% and 75% of the contract dollar value respectively" might not be applicable depending on the contract type.

p. In FDOT contracts, the monetary value of each activity is not specified, but cost per unit of each pay item is established by the bid.

q. An activity is considered weather sensitive if it is also affected by wind.

r. To qualify for time extension in resource delivery delays, the contractor must provide a proof that the delay was unforeseeable and beyond his control.

s. When the schedule is behind, increasing equipment is another method to improve productivity and the rate of progress.

t. To accelerate the schedule, an activity could be broken down into smaller activities that may be done concurrently.

2. FDOT District 2 Scheduling Engineer (Mr. Ananth Parsad)

   a. For design and submittal activities, you may split activities into 30% complete, 70% complete and 100% complete.

   b. The FDOT does not include allowance for anticipated weather delays in establishing contract time, instead, it guarantees weather days to the contractor once it occurs.

   c. Long term procurement activities (more than 30 days) should be accepted.

   d. Environmental permits should also include NPDES and EPR/DER permits.

   e. Prior to start any construction work, the project engineer should check that all properties rights, waivers and clearances had been obtained.

   f. The contractor should not tack the surface to be paved until he/she is sure that existing weather conditions is good.

   g. In freeway construction if barrier walls were used to narrow existing highway, the length of the narrowed highway should not exceed 3 miles.

3. FDOT Ocala Construction Office Resident Engineer (Mr. Richard Newsome):

   a. Field time study should be done to determine the productivity rate for construction activities.

   b. Environmental permits might also include aviation and consumption use permits.

   c. Activities that are not in the critical path need to be managed near critical.

d. A schedule showing early completion date requires a contract change to be valid.

e. In FDOT contracts, front-end-loading is acceptable.

f. Retainage on progress payment of intensive labor activities are applicable on some FDOT contracts.

g. Weather could be a factor in resource delivery delays etc., hurricanes on fabrication site.

h. The productivity rate for shoulder reworking should not be as high as 1 mile/day.

i. The productivity rate for clearing and grubbing should not be as high as 10 acre/day.

j. The productivity rate for stabilization/sub-grade should be higher than 500 SY/day.

k. The productivity rate for concrete work should not be as high as 5000 SY/day.

l. The contractor is obligated to increase staff equipment, etc. at his cost to keep the schedule on time.

4. FDOT Gainesville Construction Office Project Manager (Mr. Jamal Hasona):

a. Clearing and Grubbing activity cannot start before Maintenance of Traffic activity has started.

b. Truck Hauling Excavation activity cannot start before Clearing and Grubbing activity has started.

c. Base activity should not start before Topsoil activity.

d. Stripping activity cannot start before Roadside Signing has started.

e. Maintenance of Traffic activity should not start before Mobilization activity.

f. Erosion Maintenance activity cannot start before Maintenance of Traffic activity has started.

g. Drainage work cannot start before Regular Excavation work has started.

h. Stabilization/Sub-grade work cannot start before Clearing and Grubbing has started.

i. Regular Excavation cannot start before Clearing and Grubbing has started.

j. Drainage work can not start before Truck Hauling Excavation work has started.

k. Curb and Gutter work cannot start before Stabilization/Sub-grade has started.

l. Base Construction cannot start before Curb and Gutter has started.

m. Sidewalk work cannot start before Curb and Gutter work has started.

n. Priming cannot start before Base Construction has started.

o. Asphalt Pavement cannot start before Priming has started.

p. Stripping activity cannot start before Asphalt Pavement has started.

q. Installing Reflective Pavement Markers cannot start before Stripping has started.

r. Seeding work cannot start before Topsoil has started.

s. Sodding work cannot start before Topsoil has started.

5. Highway Construction Management Consultant Program Manager (Mr. Del Younker):

a. If liquidated damages clause exist, an initial schedule showing early completion than the specified number of contract days is not acceptable.

b. Front-end-loading practice is acceptable, but back-end-loading is not. This is because delinquency is determined by late start cash flow curve.

c. The contractor is entitled to a compensation claim, when the owner uses float to accommodate changes, only if he can prove manpower shifts/redirection using resource loading.

d. It is not true that float has more value early in the life of the project than when the project approaches completion.

e. To qualify for time extension in resource delivery delays, the contractor must provide a proof that the delay was unforeseeable and beyond his control.

f. When an activity either starts late or shows a low rate of progress, the contractor must redistribute his forces to meet the schedule.

g. The contractor should not revise the baseline schedule just because he gets behind.

5. Highway Construction Contractor Project Manager Coordinator (Ms. Carla Alford):

a. There is no one-to-one correlation between pay-items and activities.

b. Float might be used by the FDOT to accommodate changes to the project.

c. An initial schedule showing early completion than the contract completion date is not acceptable according to FDOT specifications.

d. The practice of front-end-loading is legal in FDOT contracts.

e. Retainage on payment request for labor intensive activities is applicable in some contracts.

APPENDIX B
dBASE III (DBF) FILES EXPORTED BY SURETRAK AND THE DATA CONTAINED IN EACH FILE

TABLE B-1. HWCS1.DBF FILE: CONTAINS GENERAL INFORMATION ABOUT THE PROJECT ON HAND.

Field	Name	Type	Width	Contents
001	TITLE	C	30	Project title
002	SPONSOR	C	30	Sponsor
003	REV	N	03	Revision number
004	BASEDATE	D	08	Start date
005	FNSHDATE	D	08	Finish date
006	DATADATE	D	08	Data date
007	CUTDATE	D	08	Cutoff date
008	MUSTDATE	D	08	Must finish date
009	PCTCMP	N	03	Percent complete
010	PCTEXP	N	03	Percent expended
011	GTITLE1	C	04	Group 1 title
012	GTITLE2	C	04	Group 2 title
013	GTITLE3	C	04	Group 3 title
014	WEEKLEN	N	01	Workweek length
015	WEEKSTRT	N	01	Workweek start

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-2. HWCS2.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT ONE ACTIVITY IN THE PROJECT SCHEDULE.

Field	Name	Type	Width	Contents
001	ACTNO	C	16	Activity number
002	DESC	C	48	Description
003	ORGDUR	N	03	Original duration
004	REMDUR	N	03	Remaining duration
005	PCT	N	03	Percent complete
006	TYPE	C	01	Activity type
007	GROUP1	C	04	Group code 1
008	GROUP2	C	04	Group code 2
009	GROUP3	C	04	Group code 3
010	WBSCODE	C	20	WBS code
011	ES	D	08	Early start date
012	EF	D	08	Early finish date
013	LS	D	08	Late start date
014	LF	D	08	Late finish date
015	PS	D	08	Planned start date
016	PF	D	08	Planned finish date
017	FSTART	D	08	Forced start date
018	FSTYPE	C	01	Forced start type
019	FFINISH	D	08	Forced finish date
020	FFTYPE	C	01	Forced finish type
021	AS	D	08	Actual start date
022	AF	D	08	Actual finish date
023	FF	N	04	Free float
024	TF	N	04	Total float
025	T_BUDGET	N	09	Total budget cost
026	COST_ATCMP	N	09	Total completion cost
027	REV_ATCMP	N	09	Total revenue at completion
028	COST_TOCMP	N	09	Total cost to complete
029	COST_TODAT	N	09	Total cost to date
030	E_VALUE	N	09	Total earned value
031	SCHED_COST	N	09	Total scheduled cost
032	COST_VAR	N	10	Total cost variance
033	SCHED_VAR	N	10	Total schedule variance
034	COMPL_VAR	N	10	Total completion variance
035	NET	N	10	Total net at completion

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-3. HWCS3.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT A RELATIONSHIP BETWEEN TWO ACTIVITIES.

Field	Name	Type	Width	Contents
001	PRED	C	16	Predecessor activity #
002	SUCC	C	16	Successor activity #
003	LINKTYPE	C	01	Relationship type
004	LEAD	N	03	Lead time

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-4. HWCS4.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT ONE RESOURCE CODE.

Field	Name	Type	Width	Contents
001	RCODE	C	08	Resource code
002	RDESC	C	30	Resource description
003	LIMIT	N	04	Limit per day
004	UNITCOST	N	07	Unit cost
005	UNITMEAS	C	02	Unit of measure
006	UNITVALUE	N	07	Revenue unit value
007	RUNITMEAS	C	02	Revenue unit of measure

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-5. HWCS5.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT ONE RESOURCE'S ASSIGNMENT TO AN ACTIVITY.

Field	**Name**	**Type**	**Width**	**Contents**
001	ACTNO	C	16	Activity number
002	RCODE	C	08	Resource code
003	COST PAT	C	02	Cost pattern code
004	REV PAT	C	02	Revenue pattern code
005	RATE	C	01	Allocation rate
006	UNIT/RATE	N	04	Unit allocation/rate
007	UNITBUDGET	N	04	Budget units
008	UNIT_ATD	N	04	Actual to date units
009	UNIT_ETC	N	04	Estimate complete units
010	UNIT_EAC	N	04	At completion units
011	COSTBUDGET	N	08	Budgeted costs
012	COST_ATD	N	08	Actual to date costs
013	COST_ETC	N	08	To complete costs
014	COST_EAC	N	08	At completion costs
015	REV_ATD	N	08	Revenue to date
016	REV_EAC	N	08	Revenue at completion
017	E_VALUE	N	08	Earned value

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-6. HWCS6.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT ONE GROUP CODE.

Field	**Name**	**Type**	**Width**	**Contents**
001	GCODE	C	04	Group code
002	GDESC	C	05	Group code description

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-7. HWCS7.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT NONWORK DAYS.

Field	Name	Type	Width	Contents
001	HOLIDAY	D	08	Holiday or nonwork day date

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

TABLE B-8. HWCS8.DBF FILE: EACH RECORD CONTAINS INFORMATION ABOUT ONE COST OR REVENUE CASH-FLOW PATTERN.

Field	Name	Type	Width	Contents
001	CFPAT	C	02	Cash-flow pattern code
002	CFDESC	C	20	Cash-flow pattern description
003	PAT1	C	01	First cash-flow period
004	PAT1I	N	04	First cash-flow period
005	PAT1D	C	09	First cash-flow period
006	PAT2	C	01	Second cash-flow period
007	PAT2I	N	04	Second cash-flow period
008	PAT2D	C	09	Second cash-flow period
009	PAT3	C	01	Third cash-flow period
010	PAT3I	N	04	Third cash-flow period
011	PAT3D	C	09	Third cash-flow period

SOURCE: Primavera System Inc., SURETRAK Project Scheduler 2.0 Manual (1990).

APPENDIX C
PROGRAM INTRODUCTION, COMMANDS FILES, REPORT FORMAT INSTRUCTIONS, AND KNOWLEDGE BASE RULES

Program Introduction

SUBJECT: HWCSAS (HighWay Construction Scheduling Analysis System)

AUTHOR: Marwan M. Fahmie

STARTING TEXT:

HWCSAS is a knowledge-based expert system designed to analyze and evaluate highway construction schedules. HWCSAS has the ability to analyze an initial schedules. HWCSAS is designed to access schedule's information by reading data from reports generated by a project management software (SURETRAK).

By evaluating the information produced by the project management software for the activities that make up the construction schedule, HWCSAS is able to advice the USER about the current or the expected problems the schedule may have. The results of the schedule analysis and evaluation will be tabulated and displayed. To analyze the construction schedule accurately, HWCSAS requires the user to use a correct code and description for each activity.

These codes and descriptions are tabulated in the documents accompanied with this software. For more information about running HWCSAS please refer to the dissertation titled "A Knowledge-Based Expert System Approach For The Analysis And Evaluation of Highway Construction Schedules."

ENDING TEXT:

Thank you for using HWCSAS for analyzing and evaluating your highway construction schedules. If you have any comments or questions, please! write to the following address:
Construction Engineering and Management Division
Civil Engineering Department
University of Florida
Gainesville, Fl., 32610

DERIVATION:

Apply all possible rules in data derivations.

PROBABILITY SYSTEM:

0 - 10

DISPLAY THRESHOLD:
1

List of SQL Command Files

HWCSAS.CMD

```
SQL_CONNECT("dBase LOCKING=NONE ", [DB ID])
REPORT HWCSAS1A.OUT

SQL_EXEC([DB ID], "SELECT *, VAL(DTOS(FNSHDATE)),
VAL(DTOS(MUSTDATE))FROM C:\SURETRAK\HWCS1.DBF WHERE
REV>=0", [CMD ID1])
SQL_NEXTREC([CMD ID1], [TEST FLAG1])
SQL_VALUES([CMD ID1], 1, "", [TITLE])
SQL_VALUES([CMD ID1], 2, "", [SPONSOR])
SQL_VALUES([CMD ID1], 4, "", [BASEDATE])
SQL_VALUES([CMD ID1], 5, "", [FNSHDATE])
SQL_VALUES([CMD ID1], 6, "", [DATADATE])
SQL_VALUES([CMD ID1], 8, "", [MUSTDATE])
SQL_VALUES([CMD ID1], 14, "", [WEEKLEN])
SQL_VALUES([CMD ID1], 16, "", [DATE F])
SQL_VALUES([CMD ID1], 17, "", [DATE M])
RULES 1
REPORT HWCSAS1.OUT
CLEAR R 1
CLEAR C 10
SQL_NEXTREC([CMD ID1], [TEST FLAG1])
SQL_END_SQL([CMD ID1])

SQL_EXEC([DB ID],"SELECT COUNT(*)FROM
C:\SURETRAK\HWCS2.DBF WHERE TF= 0", [CMD ID2])
SQL_NEXTREC([CMD ID2], [TEST FLAG2])
SQL_VALUES([CMD ID2], 1, "", [NCA])
SQL_EXEC([DB ID], "SELECT COUNT(*), SUM(T_BUDGET) FROM
C:\SURETRAK\HWCS2.DBF WHERE ORGDUR>=0", [CMD ID21])
SQL_NEXTREC([CMD ID21], [TEST FLAG21])
SQL_VALUES([CMD ID21], 1, "", [TOTAL ACT]
SQL_VALUES([CMD ID21], 2, "", [CONTRACT AMOUNT]
RULES 2
REPORT HWCSAS1.OUT
CLEAR R 2
CLEAR C 12
SQL_END_SQL([CMD ID2])
SQL_END_SQL([CMD ID21])

SQL_EXEC([DB ID], "SELECT *, COUNT(*), SUM(T_BUDGET)
FROM C:\SURETRAK\HWCS2.DBF WHERE ORGDUR>= 0", [CMD
ID22])
SQL_NEXTREC([CMD ID22], [TEST FLAG22])
WHILE ([TEST FLAG22] == 0)
```

```
SQL_VALUES([CMD ID22], 1, "", [ACTNO])
SQL_VALUES([CMD ID22], 2, "", [DESC])
SQL_VALUES([CMD ID22], 3, "", [ORGDUR])
SQL_VALUES([CMD ID22], 6, "", [TYPE])
SQL_VALUES([CMD ID22], 7, "", [RESPONSIBILITY])
SQL_VALUES([CMD ID22], 9, "", [UNIT MEASURE])
SQL_VALUES([CMD ID22], 10, "", [QUANTITY])
SQL_VALUES([CMD ID22], 24, "", [TOTAL FLOAT])
SQL_VALUES([CMD ID22], 25, "", [ACT COST])
SQL_VALUES([CMD ID22], 36, "", [TOTAL ACT])
SQL_VALUES([CMD ID22], 37, "", [CONTRACT AMOUNT])
RULES 3-89
REPORT HWCSAS.OUT
CLEAR R ALL
CLEAR Q ALL
CLEAR C ALL
SQL_NEXTREC([CMD ID22], [TEST FLAG22])
WEND
SQL_END_SQL([CMD ID22])

SQL_EXEC([DB ID], "UPDATE C:\SURETRAK\HWCS3.DBF SET
LINKTYPE='A' WHERE LINKTYPE <> 'S'", [CMD ID3])
SQL_EXEC([DB ID], "SELECT * FROM C:\SURETRAK\HWCS3.DBF
WHERE LEAD>=0", [CMD ID3])
SQL_NEXTREC([CMD ID3], [TEST FLAG3])
WHILE ([TEST FLAG3] == 0)
SQL_VALUES([CMD ID3], 1, "", [ACTNO])
SQL_VALUES([CMD ID3], 2, "", [SUCCESSOR])
SQL_VALUES([CMD ID3], 3, "", [LINKTYPE])
SQL_VALUES([CMD ID3], 4, "", [LEAD TIME])
RULES 90-110
REPORT HWCSAS2.OUT
CLEAR R ALL
CLEAR Q ALL
CLEAR C ALL
SQL_NEXTREC([CMD ID3], [TEST FLAG3])
WEND
SQL_END_SQL([CMD ID3])
SQL_DISCONNECT([DB ID])
```

HWCSAS.CFG

```
TRACE=HWCSAS.TRC
```

List of Report Format Instructions

HWCSAS1A.OUT

```
FILE HWCSAS1A.RPT
FIRST"Highway Construction Schedule Analysis System(HWCSAS)"
FIRST"------------------------------------------------------"
FIRST"     "
FIRST"   FDOT Highway Construction Scheduling Regulations "
FIRST"-----------------------------------------------------"
FIRST"    "
"1-   Within 21 calendar days after the contract had been
      awarded or at the preconstruction conference, which
      ever is earlier, the FDOT requires from the contractor
      to submit a work progress schedule for the project.
      The schedule shall show the various activities of work
      in sufficient detail to demonstrate that the contractor
      has a reasonable plan to complete the project on time."
"     "
"2-   Sufficient association shall be conducted and
      information provided to the FDOT to indicate
      coordination of activities with utility owners having
      facilities within the project limits.  The schedule
      shall conform to the utility adjustment schedules
      included in the contract documents unless changes are
      mutually agreed upon by the utility company, the
      contractor and the FDOT."
"     "
"3-   The FDOT District Scheduling Engineer, with the
      involvement of the Resident Engineer, reviews the
      schedule, and if it meets the contract requirements
      submits it to the District Construction Engineer for
      approval."
"     "
"4-   If the schedule submitted is determined to be
      inadequate by the FDOT Engineer, it will be returned to
      the contractor for correction.  The contractor will
      have fifteen calendar days from the date of transmittal
      to submit a correct schedule."
"     "
"5-   The FDOT establishes contract time in calendar for each
      project based on the type and volume of the work to
      be performed.  In setting the time, the FDOT considers
      weekends and holidays.  Also, the anticipated affect of
      utility adjustments or relocations on project progress
      is considered.  Under the calendar day concept,
      everyday that comes along is a chargeable day (unless
      contract time has been suspended.)"
"     "
```

```
"6-  Federal, State and Local environmental permits must be
     obtained before any work can proceed."
"    "
"7-  External constraints should be considered, including
     site access, work of other contractors, local climate
     and environmental conditions, working schedules of
     local suppliers, contract milestones, etc."
"    "
"8-  If the construction work requires narrowing the
     existing road or highway with concrete barricades, the
     length of the narrowed road or highway must not exceed
     the specified limit in length by the contract.  If the
     construction work involves more than the specified
     limit in length, the work must be divided in sections
     and scheduled in different times."
"    "
"9-  The contractor shall always conduct the work in such
     manner and sequence to insure the least practicable
     interference with traffic."
   "-------------------------------------------------------"
     C =10/T
     CLOSE
     DISPLAY HWCSAS1A.RPT
```

HWCSAS1.OUT

```
      FILE HWCSAS1.RPT
      FIRST"HighWay Construction Schedule
      Analysis(HWCSAS)Report1"

FIRST"------------------------------------------------------"
          [TITLE]
          [SPONSOR]
          [DATADATE]
          [BASEDATE
          [FNSHDATE]
          [MUSTDATE]
          [WEEKLEN]
          [NCA]
          [TOTAL ACT]
          [CONTRACT AMOUNT]



"========================================================="
          C=10/T
          CLOSE
          DISPLAY HWCSAS1.RPT
```

HWCSAS2.OUT

```
FILE HWCSAS2.RPT
FIRST" HighWay Construction Schedule Analysis Report 3"
FIRST"-----------------------------------------------------"
          [ACTNO]
          [SUCCESSOR]
          [LINKTYPE]
          [LEAD TIME]
FIRST"====================================================="
          C =10/T
          CLOSE
          DISPLAY HWCSAS2.RPT
```

List of Rules

RULE NUMBER: 1 (CMPLTN DATE COMP)

IF: [DATE F]>[DATE M]

THEN:

- The completion date must comply with the contract requirements. A schedule consuming more than the specified number of contract days is not acceptable.
- Confidence=10/10

RULE NUMBER: 2 (CRITICAL ACT %)

IF: ([NCA]/[TOTAL ACT])>0.2

THEN:

- The critical path usually consists of relatively few activities (less than 20%). A high ratio of (critical/total) activities might indicate that the contractor did not schedule the project adequately or activities' durations might been overstated for the purpose of eliminating float.
- Confidence=10/10

NOTE: Float should be diverse to support the assumption that it has not been manipulated. Zero floating a network defeats its fundamental purpose. One must know which activities are critical and which are not to effectively manage the project.

RULE NUMBER: 3 (CODES VERIFYING)

IF:

```
([ACTNO]!="1000") && ([ACTNO]!="1010") &&
([ACTNO]!="1012") && ([ACTNO]!="1014") &&
([ACTNO]!="1016") && ([ACTNO]!="1018") &&
([ACTNO]!="1019") && ([ACTNO]!="1040") &&
([ACTNO]!="1100") && ([ACTNO]!="1200") &&
([ACTNO]!="1205") && ([ACTNO]!="1206") &&
([ACTNO]!="1208") && ([ACTNO]!="1600") &&
([ACTNO]!="1750") && ([ACTNO]!="2200") &&
([ACTNO]!="3270") && ([ACTNO]!="3280") &&
([ACTNO]!="3500") && ([ACTNO]!="3600") &&
([ACTNO]!="4250") && ([ACTNO]!="4500") &&
([ACTNO]!="4550") && ([ACTNO]!="4551") &&
([ACTNO]!="4552") && ([ACTNO]!="4553") &&
```

```
([ACTNO]!="4554") && ([ACTNO]!="4555") and
([ACTNO]!="1620") && ([ACTNO]!="3000") &&
([ACTNO]!="4000") && ([ACTNO]!="4556") &&
([ACTNO]!="4557") && ([ACTNO]!="4558") &&
([ACTNO]<>"4559") && ([ACTNO]<>"4560") &&
([ACTNO]<>"4561") && ([ACTNO]<>"4562") &&
([ACTNO]<>"4563") && ([ACTNO]<>"5200") &&
([ACTNO]<>"5205") && ([ACTNO]<>"5210") &&
([ACTNO]<>"5300") && ([ACTNO]<>"5340") &&
([ACTNO]<>"5360") && ([ACTNO]<>"5450") &&
([ACTNO]<>"5460") && ([ACTNO]<>"5500") &&
([ACTNO]<>"5600") && ([ACTNO]<>"5700") &&
([ACTNO]<>"5750") && ([ACTNO]<>"5770") &&
([ACTNO]<>"5800") && ([ACTNO]<>"6300") &&
([ACTNO]<>"6500") && ([ACTNO]<>"7000") &&
([ACTNO]<>"7060") && ([ACTNO]<>"7100") &&
([ACTNO]<>"7360") && ([ACTNO]<>"9999") &&
([ACTNO]<>"99999") and  ([ACTNO]<>"1020-10")&&
([ACTNO]<>"1020-20") && ([ACTNO]<>"1020-30")&&
([ACTNO]<>"1020-40") && ([ACTNO]<>"1020-50")&&
([ACTNO]<>"1020-60") && ([ACTNO]<>"1020-70")&&
([ACTNO]<>"1020-80") && ([ACTNO]<>"1020-90")
```

THEN:

- The above activity is unknown to the HWCSAS knowledge base. Codes must be complete, correct and according to the work breakdown structure.
- Confidence=10/10

ELSE:

- The above activity's code is correct.
- Confidence=9/10

RULE NUMBER: 4 (DESC VERIFYING 1)

IF:

```
([ACTNO]="1000" && [DESC]<>"START") OR
([ACTNO]="1010" && [DESC]<>"MOBILIZATION") OR
([ACTNO]="1012" && [DESC]<>"ROADWAY SHOP
    DRAWINGS PREPARATION AND SUBMITTAL") OR
([ACTNO]="1014" && [DESC]<>"SUBMISSION OF ASPHALT
    PAVEMENT MIX FORMULA") OR
([ACTNO]="1016" && [DESC]<>"BRIDGE SHOP DRAWINGS
    PREPARATION AND SUBMITTAL") OR
([ACTNO]="1018" && [DESC]<>"SUBMISSION OF CONCRETE
    MIX DESIGN") OR
```

([ACTNO]="1019" && [DESC]<>"SUBMISSION OF DELIVERY SCHEDULE") OR
([ACTNO]="1040" && [DESC]<>"EROSION MAINTENANCE") OR
([ACTNO]="1100" && [DESC]<>"CLEARING AND GRUBBING") OR
([ACTNO]="1200" && [DESC]<>"TRUCK HAULING EXCAVATION") OR
([ACTNO]="1205" && [DESC]<>"REGULAR EXCAVATION") OR
([ACTNO]="1206" && [DESC]<>"ROADWAY EMBANKMENT") OR
([ACTNO]="1208" && [DESC]<>"ABUTMENT EMBANKMENT") OR
([ACTNO]="1600"&&[DESC]<>"STABILIZATION/SUB-GRADE") OR
([ACTNO]="1620" && [DESC]<>"TOPSOIL") OR
([ACTNO]="1750" && [DESC]<>"RESEATING EXISTING CONCRETE PAVEMENT") OR
([ACTNO]="2200" && [DESC]<>"BASE CONSTRUCTION")

THEN:

- The above activity does not have the correct description. Each activity should have a unique description and nonstandard descriptions should be avoided.
- Confidence=10/10

ELSE:

- The above activity's description is correct.
- Confidence=9/10

RULE NUMBER: 5 (DESC VERIFYING 2)

IF:

([ACTNO]="3000" && [DESC]<>"PRIMING") OR
([ACTNO]="3270" && [DESC]<>"MILLING EXISTING ASPHALT PAVEMENT") OR
([ACTNO]="3280" && [DESC]<>"RESURFACING") OR
([ACTNO]="3500" && [DESC]<>"PAVEMENT") OR
([ACTNO]="3600" && [DESC]<>"BRIDGE APPROACH SLAB") OR
([ACTNO]="4000" && [DESC]<>"RETAINING WALLS") OR
([ACTNO]="4250" && [DESC]<>"DRAINAGE") OR
([ACTNO]="4500" && [DESC]<>"PRESTRESSED CONSTRUCTION") OR
([ACTNO]="4550" && [DESC]<>"TEST PILING") OR
([ACTNO]="4551" && [DESC]<>"SEGMENTAL CASTING FACILITY MOBILIZATION") OR
([ACTNO]="4552" && [DESC]<>"FABRICATION AND

DELIVERY OF PILING") OR
([ACTNO]="4553" && [DESC]<>"SEGMENTAL FABRICATION") OR
([ACTNO]="4554" && [DESC]<>"BEAM OR GIRDER FABRICATION") OR
([ACTNO]="4555" && [DESC]<>"PILE INSTALLATION") OR
([ACTNO]="4556" && [DESC]<>"PILE CAPS OR SPREAD FOOTINGS")OR
([ACTNO]="4557" && [DESC]<>"COLUMNS") OR
([ACTNO]="4558" && [DESC]<>"PIER CAPS") OR
([ACTNO]="4559" && [DESC]<>"END BENTS")

THEN:

- The above activity does not have the correct description. Each activity should have a unique description and nonstandard descriptions should be avoided.
- Confidence=10/10

ELSE:

- The above activity's description is correct.
- Confidence=9/10

RULE NUMBER: 6 (DESC VERIFYING 3)

IF:

([ACTNO]="4560" && [DESC]<>"BEAM, GIRDER OR SEGMENT ERECTION") OR
([ACTNO]="4562" && [DESC]<>"DECK PLACEMENT") OR
([ACTNO]="4563" && [DESC]<>"PARAPETS") OR
([ACTNO]="5200" && [DESC]<>"CURB AND GUTTER") OR
([ACTNO]="5205" && [DESC]<>"SIDEWALK") OR
([ACTNO]="5300" && [DESC]<>"RIPRAP") OR
([ACTNO]="5360" && [DESC]<>"GUARDRAIL") OR
([ACTNO]="5450" && [DESC]<>"RETAINED EARTH WALL") OR
([ACTNO]="5460" && [DESC]<>"RUMBLE STRIPS") OR
([ACTNO]="5500" && [DESC]<>"FENCING") OR
([ACTNO]="5600" && [DESC]<>"PAINTING") OR
([ACTNO]="5700" && [DESC]<>"SEEDING") OR
([ACTNO]="5750" && [DESC]<>"SODDING") OR
([ACTNO]="5770" && [DESC]<>"REWORKING SHOULDERS") OR
([ACTNO]="5800" && [DESC]<>"LANDSCAPING") OR
([ACTNO]="6300" && [DESC]<>"HIGHWAY LIGHTING") OR
([ACTNO]="6500" && [DESC]<>"SIGNALIZATION") OR
([ACTNO]="7000" && [DESC]<>"ROADSIDE SIGNING") OR
([ACTNO]="7060" && [DESC]<>"REFLECTIVE PAVEMENT MARKERS") OR
([ACTNO]="7100" && [DESC]<>"STRIPPING")

THEN:

- The above activity does not have the correct description. Each activity should have a unique description and nonstandard descriptions should be avoided.
- Confidence=10/10

ELSE:

- The above activity's description is correct.
- Confidence=9/10

RULE NUMBER: 7 (DESC VERIFYING 4)

IF:

```
([ACTNO]="1020-10" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 1") OR
([ACTNO]="1020-20" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 2") OR
([ACTNO]="1020-30" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 3") OR
([ACTNO]="1020-40" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 4") OR
([ACTNO]="1020-50" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 5") OR
([ACTNO]="1020-60" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 6") OR
([ACTNO]="1020-70" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 7") OR
([ACTNO]="1020-80" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 8") OR
([ACTNO]="1020-90" && [DESC]<>"MAINTENANCE OF
    TRAFFIC 9") OR
([ACTNO]="7360" && [DESC]<>"UTILITY RELOCATION")
    OR
([ACTNO]="9999" && [DESC]<>"END OF JOB") OR
([ACTNO]="99999" && [DESC]<>"PROJECT DURATION") OR
([ACTNO]="4561" && [DESC]<>"DIAPHRAGMS") OR
([ACTNO]="5210" && [DESC]<>"PERMANENT BARRIER
    WALLS")
```

THEN:

- The above activity does not have the correct description. Each activity should have a unique description and nonstandard descriptions should be avoided.
- Confidence=10/10

ELSE:

- The above activity's description is correct.
- Confidence=9/10

RULE NUMBER: 8 (UNIT VERIFYING 1)

IF:

```
([ACTNO]="1010" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="1040" && [UNIT MEASURE]<>"ACRE") OR
([ACTNO]="1100" && [UNIT MEASURE]<>"ACRE") OR
([ACTNO]="1200" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="1205" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="1206" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="1208" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="1600" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="1620" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="1750" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="2200" && [UNIT MEASURE]<>"SY")
```

THEN:

- Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities durations and costs.
- Confidence=10/10

ELSE:

- The above activity has a correct unit measure.
- Confidence=9/10

RULE NUMBER: 9 (UNIT VERIFYING 2)

IF:

```
([ACTNO]="3000" && [UNIT MEASURE]<>"GA") OR
([ACTNO]="3270" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="3280" && [UNIT MEASURE]<>"TN") OR
([ACTNO]="3500" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="3600" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="4000" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="4250" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="4500" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="4550" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="4551" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="4552" && [UNIT MEASURE]<>"LS")
```

THEN:

- Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities durations and costs.

- Confidence=10/10

ELSE:

- The above activity has a correct unit measure.
- Confidence=9/10

RULE NUMBER: 10 (UNIT VERIFYING 3)

IF:

```
([ACTNO]="4553" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="4554" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="4555" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="4556" && [UNIT MEASURE]<>"CY") OR
([ACTNO]="4557" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="4558" && [UNIT MEASURE]<>"EA") OR
([ACTNO]="4559" && [UNIT MEASURE]<>"EA") OR
([ACTNO]="4560" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="4561" && [UNIT MEASURE]<>"EA") OR
([ACTNO]="4562" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="4563" && [UNIT MEASURE]<>"EA")
```

THEN:

- Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities durations and costs.
- Confidence=10/10

ELSE:

- The above activity has a correct unit measure.
- Confidence=9/10

RULE NUMBER: 11 (UNIT VERIFYING 4)

IF:

```
([ACTNO]="5200" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="5205" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="5210" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="5300" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="5360" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="5450" && [UNIT MEASURE]<>"SF") OR
([ACTNO]="5460" && [UNIT MEASURE]<>"PM") OR
([ACTNO]="5500" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="5600" && [UNIT MEASURE]<>"TN") OR
([ACTNO]="5700" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="5750" && [UNIT MEASURE]<>"SY")
```

THEN:

- Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities durations and costs.
- Confidence=10/10

ELSE:

- The above activity has a correct unit measure.
- Confidence=9/10

RULE NUMBER: 12 (UNIT VERIFYING 5)

IF:

```
([ACTNO]="5770" && [UNIT MEASURE]<>"SY") OR
([ACTNO]="5800" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="6300" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="6500" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="7000" && [UNIT MEASURE]<>"LS") OR
([ACTNO]="7060" && [UNIT MEASURE]<>"EA") OR
([ACTNO]="7100" && [UNIT MEASURE]<>"LF") OR
([ACTNO]="7360" && [UNIT MEASURE]<>"LS")
```

THEN:

- Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities durations and costs.
- Confidence=10/10

ELSE:

- The above activity has a correct unit measure.
- Confidence=9/10

RULE NUMBER: 13 (UNIT VERIFYING 6)

IF:

```
[ACTNO]="1000" OR [ACTNO]="9999" OR
[ACTNO]="99999" OR
[ACTNO]="1012" OR [ACTNO]="1014" OR [ACTNO]="1016"
    OR
[ACTNO]="1018" OR [ACTNO]="1019" and [UNIT
    MEASURE]!="NONE"
```

THEN:

- The above activity should not have any unit measure.
- Confidence=10/10

RULE NUMBER: 14 (UNIT VERIFYING 7)

IF:

[ACTNO]="1020-10" OR [ACTNO]="1020-20" OR
[ACTNO]="1020-30" OR [ACTNO]="1020-40" OR
[ACTNO]="1020-50" OR [ACTNO]="1020-60" OR
[ACTNO]="1020-70" OR [ACTNO]="1020-80" OR
[ACTNO]="1020-90" and [UNIT MEASURE]!="DA"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = DA (daily)
- Confidence=10/10

RULE NUMBER: 15 (UNIT VERIFYING 8)

IF:

[ACTNO]="1100" OR [ACTNO]="1040" and [UNIT MEASURE]!="ACRE"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = ACRE
- Confidence=10/10

RULE NUMBER: 16 (UNIT VERIFYING 9)

IF:

[ACTNO]="1200" OR [ACTNO]="1205" OR [ACTNO]="1206" OR
[ACTNO]="1208" OR [ACTNO]="3600" OR [ACTNO]="4000" OR
[ACTNO]="4556" and [UNIT MEASURE]!="CY"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = "CY"
- Confidence=10/10

RULE NUMBER: 17 (UNIT VERIFYING10)

IF:

[ACTNO]="1600" OR [ACTNO]="1620" OR [ACTNO]="1750" OR

[ACTNO]="2200" OR [ACTNO]="5205" OR [ACTNO]="3270"
OR
[ACTNO]="3500" OR [ACTNO]="5205" OR [ACTNO]="5300"
OR
[ACTNO]="5700" OR [ACTNO]="5750" OR [ACTNO]="5770"
and
[UNIT MEASURE]!="SY"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = SY.
- Confidence=10/10

RULE NUMBER: 18 (UNIT VERIFYING11)

IF:

[ACTNO]="3280" OR [ACTNO]="5600"
and [UNIT MEASURE]!="TN"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = TN.
- Confidence=10/10

RULE NUMBER: 19 (UNIT VERIFYIN12)

IF:

[ACTNO]="4250" OR [ACTNO]="4500" OR [ACTNO]="4550"
OR
[ACTNO]="4555" OR [ACTNO]="4557" OR [ACTNO]="5200"
OR
[ACTNO]="5210" OR [ACTNO]="5360" OR [ACTNO]="5500"
OR
[ACTNO]="7100" and [UNIT MEASURE]!="LF"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = LF.
- Confidence=10/10

RULE NUMBER: 20 (UNIT VERIFYING13)

IF:

[ACTNO]="4558" OR [ACTNO]="4559" OR [ACTNO]="4561"
OR
[ACTNO]="4563" OR [ACTNO]="7060"

and [UNIT MEASURE]!="EA"

THEN:

- According to the Department of Transportation specifications, the above activity should have a unit measure = EA (each).
- Confidence=10/10

RULE NUMBER: 21 (UNIT VERIFYING14)

IF:

[ACTNO]="1010" OR [ACTNO]="4551" OR [ACTNO]="4552" OR
[ACTNO]="4553" OR [ACTNO]="4554" OR [ACTNO]="4560" OR
[ACTNO]="4562" OR [ACTNO]="5800" OR [ACTNO]="6300" OR
[ACTNO]="6500" OR [ACTNO]="7000" OR [ACTNO]="7360"
and [UNIT MEASURE]!="LS"

THEN:

- According to the Department of Transportation Specifications, the above activity should have a unit measure= LS(lump sum).
- Confidence=10/10

RULE NUMBER: 22 (UNIT VERIFYING15)

IF:

[ACTNO]="3000"
and [UNIT MEASURE]!="GA"

THEN:

- According to The Department of Transportation Specifications, the above activity should have a unit measure = GA(Gallon).
- Confidence=10/10

RULE NUMBER: 23 (UNIT VERIFYING16)

IF:

[ACTNO]="5450"
and [UNIT MEASURE]!="SF"

THEN:

- According to The Department of Transportation Specifications, the above activity should have a unit measure = SF.
- Confidence=10/10

RULE NUMBER: 24 (UNIT VERIFYING17)

IF:
[ACTNO]="5460"
and [UNIT MEASURE]!="PM"

THEN:
- According to The Department of Transportation Specifications, the above activity should have a unit measure = PM(per mile).
- Confidence=10/10

RULE NUMBER: 25 (ACT. 1200-1 PROD)

IF:
[ACTNO]="1200"
and [QUANTITY]<100000 && [QUANTITY]>([ORGDUR]*900)

THEN:
- The productivity rate of Truck Hauling Excavation, when volume less than 100,000 CY, is typically 900 CY/day
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:
- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 26 (ACT. 1200-2 PROD)

IF:
[ACTNO]="1200"
and
([QUANTITY]>100000 OR [QUANTITY]<300000) && [QUANTITY]>([ORGDUR]*3800)

THEN:

- The productivity rate Truck Hauling Excavation , when volume between 100,000 - 300,000 CY, is typically 3,800 CY/day.
- Confidence=10/10

  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 27 (ACT. 1200-3 PROD)

IF:

[ACTNO]="1200"
and
[QUANTITY]>300000 && [QUANTITY]>([ORGDUR]*7500)

THEN:

- The productivity rate of Truck Hauling Excavation, when volume exceed 300,000 CY, is typically 7500 cy/day.
- Confidence=10/10

  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 28 (ACT. 1205-1 PROD)

IF:

[ACTNO]="1205"
and
[QUANTITY]>300000 && [QUANTITY]> (([ORGDUR]-61) *27248)

THEN:

- The productivity rate for Regular Excavation, when volume exceed 300,000, follows the equation:
  Duration = 0.0000367 Volume + 61
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 29 (ACT.1205-2 PROD)

IF:

[ACTNO]="1205"
and
[QUANTITY]>1300000 && [QUANTITY]>([ORGDUR]*27500)

THEN:

- The productivity rate for Regular Excavation, when volume exceeds 1,300,000 CY, is 27,500 CY/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 30 (ACT. 5770 PROD)

IF:

[ACTNO]="5770"
and
[QUANTITY]>([ORGDUR]*5000)

THEN:

- The productivity rate for Reworking Shoulders is 5000 SY/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 31 (ACT. 3270-1 PROD)

IF:

[ACTNO]="3270"
and
[QUANTITY]>([ORGDUR]*8000)

THEN:

- The productivity rate for Milling Existing Asphalt Concrete is 8000 SY/day but not to exceed 20 days.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 32 (ACT. 3270-2 PROD)

IF:

[ACTNO]="3270"
and
[ORGDUR]>20

THEN:

- The productivity rate for Milling Existing Asphalt Concrete is 8000 SY/day but not to exceed 20 days.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 33 (ACT. 5210 PROD)

IF:

ACTNO]="5210"
and
[QUANTITY]>([ORGDUR]*200)

THEN:

- The productivity rate for Permanent Barrier Walls is 200 LF/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 34 (ACT. 3280 PROD)

IF:

[ACTNO]="3280"
and
[QUANTITY]>([ORGDUR]*200)

THEN:

- The productivity rate for Resurfacing is 200 CY/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 35 (ACT. 2200-1 PROD)

IF:

```
[ACTNO]="2200"
    and
[QUANTITY]>260000 && [QUANTITY]>([ORGDUR]*4500)
```

THEN:

- The productivity rate of Base Construction, when volume exceed 260,000 SY, is typical 4500 SY/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 36 (ACT. 2200-2 PROD)

IF:

```
[ACTNO]="2200"
    and
([QUANTITY]<260000 OR [QUANTITY]>10000) &&
    [QUANTITY]>(([ORGDUR]-9.43)*35714)
```

THEN:

- The productivity rate of Base Construction, when volume is between 10,000 SY and 260,000 SY, follows the equation:
  Duration = 0.000028 Volume + 9.43.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 37 (ACT. 3500-1 PROD)

IF:

```
[ACTNO]="3500"
    and
[QUANTITY]>65000 && [QUANTITY]>([ORGDUR]*1000)
```

THEN:

- The productivity rate of Pavement work, when volume exceeds 65,000 Tons, is 1000 Tons/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 38 (ACT. 3500-2 PROD)

IF:

```
[ACTNO]="3500"
    and
[QUANTITY]<65000 && [QUANTITY]>(([ORGDUR]-5)*125)
```

THEN:

- The productivity rate of Pavement work, when volume is less than 65,000 Tons, follows the equation:
  Duration = 0.008 Volume + 5.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 39 (ACT. 1100 PROD)

IF:

[ACTNO]="1100"
and
[QUANTITY]>([ORGDUR]*10) OR [QUANTITY]<([ORGDUR]*1) OR [ORGDUR]>20

THEN:

- The productivity rate of Clearing and Grubbing work ranges from 1-10 acres/day depending on nature but not to exceed 20 days.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 40 (ACT. 1600 PROD)

IF:

[ACTNO]="1600"
and
[QUANTITY]>([ORGDUR]*500) OR [ORGDUR]>10

THEN:

- The productivity rate of Stabilization/Sub-grade work is typical 500 SY/day but not to exceed 10 days.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 41 (ACT. 4250 PROD)

IF:

```
[ACTNO]="4250"
    and
[QUANTITY]>([ORGDUR]*400) OR
[QUANTITY]<([ORGDUR]*100)
```

THEN:

- The productivity rate of Drainage work should range from 100 to 400 LF/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 42 (ACT. 5200 PROD)

IF:

```
[ACTNO]="5200"
    and
[QUANTITY]>([ORGDUR]*800) OR
[QUANTITY]<([ORGDUR]*400)
```

THEN:

- The productivity rate of Curb and Gutter work should range from 400 to 800 LF/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 43 (ACT. 5220 PROD)

IF:

[ACTNO]="5220"
and
[QUANTITY]>([ORGDUR]*300)

THEN:

- The productivity rate of Side Walk work should be 300 SY/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER :44 (ACT. 5700 PROD)

IF:

[ACTNO]="5700"
and
[QUANTITY]>([ORGDUR]*23500) OR [ORGDUR]>5

THEN:

- The productivity rate of Seeding work should be 23,500 Sy/day, but not to exceed 5 days.

- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 45 (ACT. 5750 PROD)

IF:

[ACTNO]="5750"
and
[QUANTITY]>([ORGDUR]*500) OR [ORGDUR]>10

THEN:

- The productivity rate of Sodding work should be 500 SY/day, but not to exceed 10 days.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 46 (ACT. 5360 PROD)

IF:

[ACTNO]="5360"
and
[QUANTITY]>([ORGDUR]*1500)

THEN:

- The productivity rate of Guardrail work is typical 1500 LF/day.
- Confidence=10/10
  and

- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 47 (ACT. 7060-1 PROD)

IF:

    [ACTNO]="7060"
        and
    [QUANTITY]>5000 && [QUANTITY]>([ORGDUR]*1000)

THEN:

- The productivity rate of installing Reflective Pavement Markers, when units exceed 5,000, is typically 1000 Units/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 48 (ACT. 7060-2 PROD)

IF:

    [ACTNO]="7060"
        and
    [QUANTITY]<5000 && [QUANTITY]>([ORGDUR]*500)

THEN:

- The productivity rate of installing Reflective Pavement Markers, when units less than 5,000, is typically 500 Units/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.

- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 49 (ACT. 1750 PROD)

IF:

[ACTNO]="1750"
and
[QUANTITY]>([ORGDUR]*5000)

THEN:

- The productivity rate of Reseating Existing Concrete Pavement is typically 5,000 SY/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 50 (ACT. 6500 PROD)

IF:

[ACTNO]="6500"
and
[QUANTITY]>([ORGDUR]/15)

THEN:

- The productivity rate of Signalization work is typically 15 days/Intersection.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 51 (ACT. 6300 PROD)

IF:

[ACTNO]="6300"
and
[QUANTITY]>([ORGDUR]*5)

THEN:

- The productivity rate of Lighting work is typically 5 Standard/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 52 (ACT. 5500-1 PROD)

IF:

[ACTNO]="5500"
and
[QUANTITY]<10000 && [QUANTITY]>([ORGDUR]*500)

THEN:

- The productivity rate of fencing work when length is less than 10,000 LF, is typically 500 LF/day.
- Confidence=10/10
  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 53 (ACT. 5500-2 PROD)

IF:

```
[ACTNO]="5500"
    and
[QUANTITY]>10000 && [QUANTITY]>([ORGDUR]*1200)
```

THEN:

- The productivity rate of fencing work when length is more than 10,000 LF, is typically 1200 LF/day.
- Confidence=10/10

  and
- Check the duration estimate for the above activity.
- Confidence=10/10

NOTE:

- Durations should be based on previous documented experience of the organization, historical performance, quoted data from subcontractors and vendors and on the time of the year the activity to be executed.

RULE NUMBER: 54 (ACT. DUR. LIMITS)

IF:

```
[ACTNO]="1010" OR [ACTNO]="1012" OR [ACTNO]="1014"
    OR
[ACTNO]="1016" OR [ACTNO]="1018" OR [ACTNO]="1019"
    OR
[ACTNO]="1040" OR [ACTNO]="1100" OR [ACTNO]="1200"
    OR
[ACTNO]="1205" OR [ACTNO]="1206" OR [ACTNO]="1208"
    OR
[ACTNO]="1600" OR [ACTNO]="1750" OR [ACTNO]="2200"
    OR
[ACTNO]="3270" OR [ACTNO]="3280" OR [ACTNO]="3500"
    OR
[ACTNO]="3600" OR [ACTNO]="4250" OR [ACTNO]="4500"
    OR
[ACTNO]="4550" OR [ACTNO]="4551" OR [ACTNO]="4552"
    OR
```

```
[ACTNO]="4553" OR [ACTNO]="4554" OR [ACTNO]="4555"
    and
[ACTNO]="1620" OR [ACTNO]="3000" OR [ACTNO]="4000"
    OR
[ACTNO]="4556" OR [ACTNO]="4557" OR [ACTNO]="4558"
    OR
[ACTNO]="4559" OR [ACTNO]="4560" OR [ACTNO]="4561"
    OR
[ACTNO]="4562" OR [ACTNO]="4563" OR [ACTNO]="5200"
    OR
[ACTNO]="5205" OR [ACTNO]="5210" OR [ACTNO]="5300"
    OR
[ACTNO]="5340" OR [ACTNO]="5360" OR [ACTNO]="5450"
    OR
[ACTNO]="5460" OR [ACTNO]="5500" OR [ACTNO]="5600"
    OR
[ACTNO]="5700" OR [ACTNO]="5750" OR [ACTNO]="5770"
    OR
[ACTNO]="5800" OR [ACTNO]="6300" OR [ACTNO]="6500"
    OR
[ACTNO]="7000" OR [ACTNO]="7060" OR [ACTNO]="7100"
    OR
[ACTNO]="7360" and
[ACTNO]="1020-10" OR [ACTNO]="1020-20" OR
[ACTNO]="1020-30" OR [ACTNO]="1020-40" OR
[ACTNO]="1020-50" OR [ACTNO]="1020-60" OR
[ACTNO]="1020-70" OR [ACTNO]="1020-80" OR
[ACTNO]="1020-90" and [ORGDUR]<1 OR [ORGDUR]>22
```

THEN:

- A typical activity's duration should be between 1 and 22 days. Long durations activities are difficult to measure and they usually indicate the aggregation of many sub-activities. An activity with long duration, low value and low float, may be regarded as unimportant and allowed to keep its duration.
- Confidence=10/10

RULE NUMBER: 55 (CR.ACT. DUR.LMTS)

IF:

```
[ACTNO]="1010" OR [ACTNO]="1012" OR [ACTNO]="1014"
    OR
[ACTNO]="1016" OR [ACTNO]="1018" OR [ACTNO]="1019"
    OR
[ACTNO]="1040" OR [ACTNO]="1100" OR [ACTNO]="1200"
    OR
[ACTNO]="1205" OR [ACTNO]="1206" OR [ACTNO]="1208"
    OR
```

```
[ACTNO]="1600" OR [ACTNO]="1750" OR [ACTNO]="2200"
    OR
[ACTNO]="3270" OR [ACTNO]="3280" OR [ACTNO]="3500"
    OR
[ACTNO]="3600" OR [ACTNO]="4250" OR [ACTNO]="4500"
    OR
[ACTNO]="4550" OR [ACTNO]="4551" OR [ACTNO]="4552"
    OR
[ACTNO]="4553" OR [ACTNO]="4554" OR [ACTNO]="4555"
    and
[ACTNO]="1620" OR [ACTNO]="3000" OR [ACTNO]="4000"
    OR
[ACTNO]="4556" OR [ACTNO]="4557" OR [ACTNO]="4558"
    OR
[ACTNO]="4559" OR [ACTNO]="4560" OR [ACTNO]="4561"
    OR
[ACTNO]="4562" OR [ACTNO]="4563" OR [ACTNO]="5200"
    OR
[ACTNO]="5205" OR [ACTNO]="5210" OR [ACTNO]="5300"
    OR
[ACTNO]="5340" OR [ACTNO]="5360" OR [ACTNO]="5450"
    OR
[ACTNO]="5460" OR [ACTNO]="5500" OR [ACTNO]="5600"
    OR
[ACTNO]="5700" OR [ACTNO]="5750" OR [ACTNO]="5770"
    OR
[ACTNO]="5800" OR [ACTNO]="6300" OR [ACTNO]="6500"
    OR
[ACTNO]="7000" OR [ACTNO]="7060" OR [ACTNO]="7100"
    OR
[ACTNO]="7360" and
[ACTNO]="1020-10" OR [ACTNO]="1020-20" OR
[ACTNO]="1020-30" OR [ACTNO]="1020-40" OR
[ACTNO]="1020-50" OR [ACTNO]="1020-60" OR
[ACTNO]="1020-70" OR [ACTNO]="1020-80" OR
[ACTNO]="1020-90"
    and
[TOTAL FLOAT]=0 && [ORGDUR]>15
```

THEN:

- A typical critical activity's duration should not exceed 15 days or one pay period, to allow for enough details.
- Confidence=10/10

RULE NUMBER: 56 (ADMNST ACT COST)

IF:

```
[ACTNO]="1012" OR [ACTNO]="1014" OR [ACTNO]="1016"
    OR
[ACTNO]="1018" OR [ACTNO]="1019" and [ACT COST]>0
```

THEN:

- The monetary value of administrative activities like submittal should be zero. The cost of preparing submittal is considered part of the overhead and the contractor must distribute costs to other activities.
- Confidence=10/10

RULE NUMBER: 57 (UNIT PRICE 1100)

IF:

[ACTNO]="1100"
and
([ACT COST]/[QUANTITY])>4854.11

THEN:

- The average unit price for Clearing and Grubbing is $4854.11/Acre .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 58 (UNIT PRICE 1200)

IF:

[ACTNO]="1200"
and
([ACT COST]/[QUANTITY])>3.73

THEN:

- The average unit price for Truck Hauling Excavation is $3.73/CY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 59 (UNIT PRICE 1205)

IF:

[ACTNO]="1205"
and
([ACT COST]/[QUANTITY])>2.78

THEN:

- The average unit price for Regular Excavation is $2.78/CY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 60 (UNIT PRICE 1206)

IF:

[ACTNO]="1206"
and
([ACT COST]/[QUANTITY])>7.00

THEN:

- The average unit price for Roadway Embankment is $7.00/CY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 61 (UNIT PRICE 1600)

IF:

[ACTNO]="1600"
and
([ACT COST]/[QUANTITY])>1.31

THEN:

- The average unit price for Stabilization/Sub-grade is $1.31/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 62 (UNIT PRICE 1620)

IF:

[ACTNO]="1620"
and
([ACT COST]/[QUANTITY])>0.42

THEN:

- The average unit price for Topsoil is $0.42/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 63 (UNIT PRICE 1750)

IF:

[ACTNO]="1750"
and
([ACT COST]/[QUANTITY])>0.28

THEN:

- The average unit price for Reseating Concrete Pavement is $0.28/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 64 (UNIT PRICE 3000)

IF:

[ACTNO]="3000"
and
([ACT COST]/[QUANTITY])>1.41

THEN:

- The average unit price for Base Priming is $1.41/GA.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 65 (UNIT PRICE 3280)

IF:

[ACTNO]="3280"
and
([ACT COST]/[QUANTITY])>27.69

THEN:

- The average unit price for Resurfacing is $27.69/CY.
- Confidence=10/10
  and

- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 66 (UNIT PRICE 3600)

IF:

```
[ACTNO]="3600"
    and
([ACT COST]/[QUANTITY])>273.28
```

THEN:

- The average unit price for Approaching Concrete Slab is $273.28/CY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 67 (UNIT PRICE 4000)

IF:

```
[ACTNO]="4000"
    and
([ACT COST]/[QUANTITY])>43.32
```

THEN:

- The average unit price for Retaining Walls is $43.32/SF .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 68 (UNIT PRICE 5700)

IF:

[ACTNO]="5700"
and
([ACT COST]/[QUANTITY])>0.05

THEN:

- The average unit price for Seeding is $0.05/SY.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 69 (UNIT PRICE 5770)

IF:

[ACTNO]="5770"
and
([ACT COST]/[QUANTITY])>0.45

THEN:

- The average unit price for Shoulder Reworking is $0.45/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should onform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 70 (UNIT PRICE 2200)

IF:

```
[ACTNO]="2200"
    and
([ACT COST]/[QUANTITY])<3.65
    OR
([ACT COST]/[QUANTITY])>18.00
```

THEN:

- The average unit price for Base Construction ranges between $3.65/SY and $18.00/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 71 (UNIT PRICE 3270)

IF:

```
[ACTNO]="3270"
    and
([ACT COST]/[QUANTITY])<0.47 OR
([ACT COST]/QUANTITY])>1.22
```

THEN:

- The average unit price for Milling Existing Asphalt Pavement ranges between $0.47/SY and $1.22/SY.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 72 (UNIT PRICE 3500)

IF:
    [ACTNO]="3500"
        and
    ([ACT COST]/[QUANTITY])<1.81 OR
    ([ACT COST]/[QUANTITY])>9.30

THEN:
- The average unit price for Asphalt Pavement ranges between $1.81/SY and $9.30/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:
The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 73 (UNIT PRICE 5200)

IF:
    [ACTNO]="5200"
        and
    ([ACT COST]/[QUANTITY])<6.11 OR
    ([ACT COST]/[QUANTITY])>26.10

THEN:
- The average unit price for Curb and Gutter ranges between $6.11/LF and $26.10/LF .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:
The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 74 (UNIT PRICE 5205)

IF:
    [ACTNO]="5205"
        and

([ACT COST]/[QUANTITY])<11.75 OR
([ACT COST]/[QUANTITY])>19.86

THEN:

- The average unit price for Sidewalk ranges between $11.75/SY and $19.86/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 75 (UNIT PRICE 5210)

IF:

[ACTNO]="5210"
and
([ACT COST]/[QUANTITY])<29.66 OR
([ACT COST]/[QUANTITY])>73.37

THEN:

- The average unit price for Permanent Barrier Walls ranges between $29.66/LF and $73.37/LF.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 76 (UNIT PRICE 5300)

IF:

[ACTNO]="5300"
and
([ACT COST]/[QUANTITY])<33.70 OR
([ACT COST]/[QUANTITY])>55.94

THEN:

- The average unit price for Riprap ranges between $33.70/SY and $55.94/SY .
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 77 (UNIT PRICE 5360)

IF:

```
[ACTNO]="5360"
    and
([ACT COST]/[QUANTITY])<5.32 OR
([ACT COST]/[QUANTITY])>22.30
```

THEN:

- The average unit price for Guardrail ranges between $5.32/LF and $22.30/LF.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 78 (UNIT PRICE 5460)

IF:

```
[ACTNO]="5460"
    and
([ACT COST]/[QUANTITY])<27000 OR
([ACT COST]/[QUANTITY])>32485
```

THEN:

- The average unit price for Rumble Strips ranges between $27000.00/Mile and $32485.00/Mile.

- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 79 (UNIT PRICE 5500)

IF:

[ACTNO]="5500"
and
([ACT COST]/[QUANTITY])<2.13 OR
([ACT COST]/[QUANTITY])>8.95

THEN:

- The average unit price for Fencing ranges between $2.13/LF and $8.95/LF.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 80 (UNIT PRICE 5750)

IF:

[ACTNO]="5750"
and
([ACT COST]/[QUANTITY])<1.04 OR
([ACT COST]/[QUANTITY])>1.99

THEN:

- The average unit price for Sodding ranges between $1.04/SY and $1.99/SY.
- Confidence=10/10
  and
- Check the activity cost for the above activity.

- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 81 (UNIT PRICE 7060)

IF:

[ACTNO]="7060"
and
([ACT COST]/[QUANTITY])<3.00 OR
([ACT COST]/[QUANTITY])>3.74

THEN:

- The average unit price for Installing Reflective Pavement Markers ranges between $1.04/SY and $1.99/SY.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 82 (UNIT PRICE 7100)

IF:

[ACTNO]="7100"
and
([ACT COST]/[QUANTITY])<0.17 OR
([ACT COST]/[QUANTITY])>1.47

THEN:

- The average unit price for Stripping ranges between $0.17/LF and $1.47/LF.
- Confidence=10/10
  and
- Check the activity cost for the above activity.
- Confidence=10/10

NOTE:

The monetary value of each activity should conform to the range specified in the contract and it should represent a reasonable amount for that work.

RULE NUMBER: 83 (HIGH FLOAT ACT)

IF:

[TOTAL FLOAT]>10

THEN:

- Activities with high float are not recommended. Although the activity's logic may be correct, this implies that the activity has not been integrated to optimize manpower and other resources.
- Confidence=10/10

NOTE:

Float is of more value early in the life of the job than when the job approaches completion, because as the job progress, the remaining risk factors diminish. For a given activity, float increases in value inversely to its quantity because uncontrollable events causing small periods of delay are more likely to happen than those producing longer delays.

RULE NUMBER: 84 (MAJOR SUBCNTRCTR)

IF:

[RESPONSIBILITY]!="MAIN"
and
[ACTNO]!="1000" OR [ACTNO]!="9999" OR [ACTNO]!="99999" and ([ACT COST]/[CONTRACT AMOUNT])>.10

THEN:

- Subcontractors performing 10% or more of the total contract work are considered major subcontractors, and should participate in the contractor's development plan.
- Confidence=10/10

NOTE:

Subcontractor plans should be an integral part of the construction schedule. Individuals of a particular trade should be able to see a

detailed description of their tasks with interfaces to the general plan.

RULE NUMBER: 85 (ACT 2200 CNSTRNT)

IF:
[ACTNO]="2200"

THEN:

- Before placing base material, the Inspector must make sure the sub-grade is firm and unyielding, has passed bearing test, and meets grade and cross section requirements.

- Confidence=10/10

RULE NUMBER: 86 (ACT 3500 CNSTRNT)

IF:
[ACTNO]="3500"

THEN:

- Asphalt plant operations should never be started until the weather conditions at the lay-down site are suitable for placing the mix. Temperature should not be less than 40 F or more than 120 F. If wind is blowing to the extent that dust, fine sand and debris are being deposited on the tacked surface that is being paved, then operation should be ceased.
- Confidence=10/10

RULE NUMBER: 87 (ACT 3000 CNSTRNT)

IF:
[ACTNO]="3000"

THEN:

- The base must be permitted to cure before the prime coat is applied. The moisture content must not exceed 90% of the optimum moisture at the time of priming.
- Confidence=10/10

RULE NUMBER: 88 (ACT 1100 CNSTRNT)

IF:
[ACTNO]="1100"

THEN:
- Prior to starting the Clearing and Grubbing operations, the Project Engineer should check that all permits, property rights, waivers, archaeological clearances and property easements have been obtained and are in order.
- Confidence=10/10

RULE NUMBER: 89 (RESPONS. CENTERS)

IF:
[RESPONSIBILITY]="MAIN" OR [RESPONSIBILITY]="SUB" OR [RESPONSIBILITY]="NONE"

THEN:
- Responsibility centers for each activity should be identified. These centers may be either individuals or organizational entity.
- Confidence=8/10

ELSE:
- Responsibility centers for each activity should be identified. These centers may be either individuals or organizational entity.
- Confidence=10/10

RULE NUMBER: 90 (F-S CONSTRAINTS)

IF:
[LEAD TIME]>0 && [LINKTYPE]="A"

THEN:
- The lead time of an activity with Finish to Start constraint should be defined as an activity that represent a definable project effort.
- Confidence=10/10

NOTE:
Lags on Finish-to-Start constraints usually suggest date fixing. All lag values must represent time consumed by effort for valid

time reserve calculations. To be valid, a lag on a Finish-to-Start constraint could be replaced with an activity that represents definable project effort.

RULE NUMBER: 91 (S-S CONSTRAINTS)

IF:

[LEAD TIME]=0 && [LINKTYPE]="S"

THEN:

- An activity with Start to Start constraint should not have a lead time equal to zero. The absence of this lead time indicates improper modeling of activity overlap. The value of the lead time should be less than the predecessor activity's duration.
- Confidence=10/10

RULE NUMBER: 92 (F-F CONSTRAINTS)

IF:

[LEAD TIME]>0 && [LINKTYPE]="F"

THEN:

- An activity with Finish to Finish constraint should have a lead time not equal to zero. The absence of this lead time normally indicates improper modeling of activity overlap. The value of lead time should also be less than the successor activity's duration.
- Confidence=10/10

RULE NUMBER: 93 (ACT INTRRLATN 1)

IF:

[SUCCESSOR]="1010"
and [ACTNO]="1020-10"

THEN:

- Maintenance of Traffic activity should not start before Mobilization activity.
- Confidence=10/10

RULE NUMBER: 94 (ACT INTRRLATN 2)

IF:

[SUCCESSOR]="1020-10"
and [ACTNO]="1040"

THEN:

- Erosion Maintenance activity can not start before Maintenance of Traffic activity has started.
- Confidence=10/10

RULE NUMBER: 95 (ACT INTRRLATN 3)

IF:

[SUCCESSOR]="1020-10"
and [ACTNO]="1100"

THEN:

- Clearing and Grubbing activity can not start before Maintenance of Traffic activity has started.
- Confidence=10/10

RULE NUMBER: 96 (ACT INTRRLATN 4)

IF:

[SUCCESSOR]="1100"
and [ACTNO]="1200"

THEN:

- Truck Hauling Excavation activity can not start before Clearing and Grubbing activity has started.
- Confidence=10/10

RULE NUMBER: 97 (ACT INTRRLATN 5)

IF:

[SUCCESSOR]="1100"
and [ACTNO]="1205"

THEN:

- Regular Excavation can not start before Clearing and Grubbing has started.
- Confidence=10/10

RULE NUMBER: 98 (ACT INTRRLATN 6)

IF:
[SUCCESSOR]="1200"
and [ACTNO]="4250"

THEN:
- Drainage work can not start before Truck Hauling Excavation work has started.
- Confidence=10/10

RULE NUMBER: 99 (ACT INTRRLATN 7)

IF:
[SUCCESSOR]="1205"
and [ACTNO]="4250"

THEN:
- Drainage work can not start before Regular Excavation work has started.
- Confidence=10/10

RULE NUMBER: 100 (ACT INTRRLATN 8)

IF:
[SUCCESSOR]="1100"
and [ACTNO]="1600"

THEN:
- Stabilization/Sub-grade work can not start before Clearing and Grubbing has started.
- Confidence=10/10

RULE NUMBER: 101 (ACT INTRRLATN 9)

IF:
[SUCCESSOR]="1600"
and [ACTNO]="5200"

THEN:
- Curb and Gutter work can not start before Stabilization/Sub-grade has started.
- Confidence=10/10

RULE NUMBER: 102 (ACT INTRRLATN 10)

IF:
[SUCCESSOR]="5200"

and [ACTNO]="2200"

THEN:

- Base Construction can not start before Curb and Gutter has started.
- Confidence=10/10

RULE NUMBER: 103 (ACT INTRRLATN 11)

IF:

[SUCCESSOR]="5200"
and [ACTNO]="5205"

THEN:

- Sidewalk work can not start before Curb and Gutter work has started.
- Confidence=10/10

RULE NUMBER: 104 (ACT INTRRLATN 12)

IF:

[SUCCESSOR]="2200"
and [ACTNO]="3000"

THEN:

- Priming can not start before Base Construction has started.
- Confidence=10/10

RULE NUMBER: 105 (ACT INTRRLATN 13)

IF:

[SUCCESSOR]="3000"
and [ACTNO]="3500"

THEN:

- Asphalt Pavement can not start before Priming has started.
- Confidence=10/10

RULE NUMBER: 106 (ACT INTRRLATN 14)

IF:

[SUCCESSOR]="7000"
and [ACTNO]="7100"

THEN:

- Stripping activity can not start before Roadside Signing has started.
- Confidence=10/10

RULE NUMBER: 107 (ACT INTRRLATN 15)

IF:

[SUCCESSOR]="3500"
and [ACTNO]="7100"

THEN:

- Stripping activity can not start before Asphalt Pavement has started.
- Confidence=10/10

RULE NUMBER: 108 (ACT INTRRLATN 16)

IF:

[SUCCESSOR]="7100"
and [ACTNO]="7060"

THEN:

- Installing Reflective Pavement Markers can not start before Stripping has started.
- Confidence=10/10

RULE NUMBER: 109 (ACT INTRRLATN 17)

IF:

[SUCCESSOR]="1620"
and [ACTNO]="5700"

THEN:

- Seeding work can not start before Topsoil has started.
- Confidence=10/10

RULE NUMBER: 110 (ACT INTRRLATN 18)

IF:

[SUCCESSOR]="1620"
and [ACTNO]="5750"

THEN:

- Sodding work can not start before Topsoil has started.
- Confidence=10/10.

APPENDIX D
EXAMPLES OF ACTUAL INITIAL HIGHWAY CONSTRUCTION SCHEDULES EVALUATION

Case Study I

Time Scale Report by Activity Number

```
PROJECT: Florida Highway Construction 1    START DATE: 28FEB94
SPONSOR: Civil Engineering Department      FINISH DATE: 16MAR94
>==>Critical >-->Non-Critical >..>Free Float >++>Completed *Milestone
--------------------------------------------------------------------------
Activity                          1994 FEB  MAR
Number                                 28   01   02   03   04   07   08   09   10
--------------------------------------------------------------------------
1000        START                     *    .    .    .    .    .    .    .    .
1010        MOBILIZATION              >-------->    .    .    .    .    .    .
1020-10     MAINTENANCE OF TRAFFIC    |    >------------------------------------
1040        EROSION MAINTENANCE       |    >------------------------------------
1100        CLEARING AND GRUBBING     |    >--->    .    .    .    .    .    .
1205        REGULAR EXCAVATION        |    >------------>...>    .    .    .
1600        STABILIZATION/SUB-GRADE   |    .    .    .    .    >===>    .    .
2200        BASE CONSTRUCTION         |    .    .    >---------------->.......
3000        PRIMING                   |    .    .    .    .    .    .    .    >===
3270        MILLING EXISTING PAVMNT   |    .    .    .    .    .    >========>
3500        PAVEMENT                  |    .    .    .    .    .    .    .    .
5200        CURB AND GUTTER           |    >---------------->    .    .    .
5205        SIDEWALK                  >--->    .    .    .    .    .    .    .
5700        SEEDING                   |    .    >--->    .    .    .    .    .
5750        SODDING                   |    .    .    >--->....................
7060        REFLECTIVE PAVEMENT MAR   |    .    .    .    .    .    .    .    .
7100        STRIPPING                 |    .    .    .    .    .    .    .    .
7360        UTILITY RELOCATION        >===================>    .    .    .
9999        END OF JOB                |    .    .    .    .    .    .    .    .
99999       PROJECT DURATION          >]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
```

Time Scale Report by Activity Number--Continued

```
PROJECT: Florida Highway Cnstruction 1      START DATE: 28FEB94
SPONSOR: Civil Engineering Department       FINISH DATE: 16MAR94
 >==>Critical  >-->Non-Critical  >..>Free Float  >++>Completed
--------------------------------------------------------------
Activity                         1994 MAR
Number                                11   14   15   16   17   18
--------------------------------------------------------------
1000        START                     .    .    .    .    .    .
1010        MOBILIZATION              .    .    .    .    .    .
1020-10     MAINTENANCE OF TRAFFIC    ------------>...>    .
1040        EROSION MAINTENANCE       >...............>    .
1100        CLEARING AND GRUBBING     .    .    .    .    .    .
1205        REGULAR EXCAVATION        .    .    .    .    .    .
1600        STABILIZATION/SUB-GRADE.       .    .    .    .    .
2200        BASE CONSTRUCTION         ....>     .    .    .    .
3000        PRIMING                   ====>     .    .    .    .
3270        MILLING EXISTING PAVMNT.       .    .    .    .    .
3500        PAVEMENT                  >========>     .    .    .
5200        CURB AND GUTTER           .    .    .    .    .    .
5205        SIDEWALK                  .    .    .    .    .    .
5700        SEEDING                   .    .    .    .    .    .
5750        SODDING                   ........>      .    .    .
7060        REFLECTIVE PAVEMENT MAR.       .    .    >===>     .
7100        STRIPPING                 .    .    >===>     .    .
7360        UTILITY RELOCATION        .    .    .    .    .    .
9999        END OF JOB                .    .    .    .    *    .
99999       PROJECT DURATION          ]]]]]]]]]]]]]]]]>    .
```

Network Report by Activity Number

PROJECT: Florida Highway construction 1 — START DATE: 28FEB94
SPONSOR: Civil Engineering Department — FINISH DATE: 16MAR94

PREDECESSOR NO. AND DESCRIPTION / ACTIVITY NO. AND DESCRIPTION / SUCCESSOR NO. AND DESCRIPTION		RE TYPE	LEAD TIME	DUR	-EARLY START	DATES- FINISH	TOTAL FLOAT
1000	START			0	28FEB94	25FEB94	0
7360	UTILITY RELOCATION		0		28FEB94		0
1010	MOBILIZATION		0		28FEB94		1
99999	PROJECT DURATION		0		28FEB94		0
1000	START		0			25FEB94	0
1010	MOBILIZATION			2	28FEB94	01MAR94	1
1020-10	MAINTENANCE OF TRAFFIC 1	S	1		01MAR94		1
1100	CLEARING AND GRUBBING	S	1		01MAR94		7
1205	REGULAR EXCAVATION	S	1		01MAR94		1
1040	EROSION MAINTENANCE	S	1		01MAR94		4
1010	MOBILIZATION	S	1		28FEB94		1
1020-10	MAINTENANCE OF TRAFFIC 1			11	01MAR94	15MAR94	1
9999	END OF JOB		0		17MAR94		0
1010	MOBILIZATION	S	1		28FEB94		1
1040	EROSION MAINTENANCE			8	01MAR94	10MAR94	4
9999	END OF JOB		0		17MAR94		0
1010	MOBILIZATION	S	1		28FEB94		1
1100	CLEARING AND GRUBBING			1	01MAR94	01MAR94	7
5700	SEEDING		0		02MAR94		7
1010	MOBILIZATION	S	1		28FEB94		1
1205	REGULAR EXCAVATION			3	01MAR94	03MAR94	1
1600	STABILIZATION/SUB-GRADE		0		07MAR94		0
1205	REGULAR EXCAVATION		0			03MAR94	1
7360	UTILITY RELOCATION		0			04MAR94	0
1600	STABILIZATION/SUB-GRADE			1	07MAR94	07MAR94	0
3270	MILLING EXISTING PAVEMNT		0		08MAR94		0
5200	CURB AND GUTTER	S	2		01MAR94		3
2200	BASE CONSTRUCTION			4	03MAR94	08MAR94	3
3000	PRIMING	S	2		10MAR94		0
2200	BASE CONSTRUCTION	S	2		03MAR94		3
3270	MILLING EXISTING PAVEMNT		0			09MAR94	0
3000	PRIMING			2	10MAR94	11MAR94	0
3500	PAVEMENT	S	1		11MAR94		0

Network Report by Activity Number--Continued

PROJECT: Florida Highway const. Project — START DATE: 28FEB94
SPONSOR: Civil Engineering Department — FINISH DATE: 16MAR94

PREDECESSOR NO. / ACTIVITY NO. / SUCCESSOR NO.	AND DESCRIPTION	RE TYPE	LEAD TIME	DUR	-EARLY DATES- START	FINISH	TOTAL FLOAT
1600	STABILIZATION/SUB-GRADE		0			07MAR94	0
3270	MILLING EXISTING PAVEMENT			2	08MAR94	09MAR94	0
3000	PRIMING		0		10MAR94		0
3000	PRIMING	S	1		10MAR94		0
3500	PAVEMENT			2	11MAR94	14MAR94	0
7100	STRIPPING		0		15MAR94		0
5205	SIDEWALK		0			28FEB94	3
5200	CURB AND GUTTER			4	01MAR94	04MAR94	3
2200	BASE CONSTRUCTION	S	2		03MAR94		3
5205	SIDEWALK			1	28FEB94	28FEB94	3
5200	CURB AND GUTTER		0		01MAR94		3
1100	CLEARING AND GRUBBING		0			01MAR94	7
5700	SEEDING			1	02MAR94	02MAR94	7
5750	SODDING		0		03MAR94		7
5700	SEEDING		0			02MAR94	7
5750	SODDING			1	03MAR94	03MAR94	7
7100	STRIPPING		0		15MAR94		0
7100	STRIPPING		0			15MAR94	0
7060	REFLECTIVE PAVEMENT MARKER			1	16MAR94	16MAR94	0
9999	END OF JOB		0		17MAR94		0
3500	PAVEMENT		0			14MAR94	0
5750	SODDING		0			03MAR94	7
7100	STRIPPING			1	15MAR94	15MAR94	0
7060	REFLECTIVE PAVEMENT MARK		0		16MAR94		0
1000	START		0			25FEB94	0
7360	UTILITY RELOCATION			5	28FEB94	04MAR94	0
1600	STABILIZATION/SUB-GRADE		0		07MAR94		0
1020-10	MAINTENANCE OF TRAFFIC 1		0			15MAR94	1
1040	EROSION MAINTENANCE		0			10MAR94	4
7060	REFLECTIVE PAVEMENT MARK		0			16MAR94	0
9999	END OF JOB			0	17MAR94	16MAR94	0
1000	START		0			25FEB94	0
99999	PROJECT DURATION			13	28FEB94	16MAR94	0

Results

Highway Construction Schedule Analysis System (HWCSAS)

FDOT Highway Construction Scheduling Regulations

1- Within 21 calendar days after the contract had been awarded or at the preconstruction conference, which ever is earlier, the FDOT requires from the contractor to submit a work progress schedule for the project. The schedule shall show the various activities of work in sufficient detail to demonstrate that the contractor has a reasonable plan to complete the project on time.

2- Sufficient association shall be conducted and information provided to the FDOT to indicate coordination of activities with utility owners having facilities within the project limits. The schedule shall conform to the utility adjustment schedules included in the contract documents unless changes are mutually agreed upon by the utility company, the contractor and the FDOT.

3- The FDOT District Scheduling Engineer, with the involvement of the Resident Engineer, reviews the schedule, and if it meets the contract requirements submits it to the District Construction Engineer for approval.

4- If the schedule submitted is determined to be inadequate by the FDOT Engineer, it will be returned to the contractor for correction. The contractor will have fifteen calendar days from the date of transmittal to submit a correct schedule.

5- The FDOT establishes contract time in calendar for each project based on the type and volume of the work to be performed. In setting the time, the FDOT considers weekends and holidays. Also, the anticipated affect of utility adjustments or relocations on project progress is considered. Under the calendar day concept, everyday that comes along is a chargeable day (unless contract time has been suspended.)

6- Federal, State and Local environmental permits must be obtained before any work can proceed.

7- External constraints should be considered, including site access, work of other contractors,

local climate and environmental conditions, working schedules of local suppliers, contract milestones, etc.

8- If the construction work requires narrowing the existing road or highway with concrete barricades, the length of the narrowed road or highway must not exceed the specified limit in length by the contract. If the construction work involves more than the specified limit in length, the work must be divided in sections and scheduled in different times.

9- The contractor shall always conduct the work in such manner and sequence to insure the least practicable interference with traffic.

HighWay Construction Schedule Analysis (HWCSAS) Report 1

Project Title = Florida Highway const. Project
Project Owner = Civil Engineering Department
Data Date = 2/7/94
Start Date = 2/28/94
Planned Finish Date = 3/16/94
Contract Must Finish Date = 4/1/94
Working Days/Week = 5
Total No. Of Critical Activities = 10
Total Number Of Activities = 20
Total Contract Amount = 181950

==

- The critical path usually consists of relatively few activities (less than 20%). A high ratio of (critical/total) activities might indicate that the contractor did not schedule the project adequately or activities' durations might been overstated for the purpose of eliminating float.

==

HighWay Construction Schedule Analysis (HWCSAS) Report 2

Activity Number = 1000
Activity Description = START
Activity's Duration = 0
Activity's Type = ACT
Activity's Unit Measure = NONE
Activity's Quantity = 0
Responsible Party = NONE
Activity's Total Float = 0

Activity Cost = 0

===

Activity Number = 1010
Activity Description = MOBILIZATION
Activity's Duration = 2
Activity's Type = ACT
Activity's Unit Measure = LS
Activity's Quantity = 1
Responsible Party = MAIN
Activity's Total Float = 1
Activity Cost = 5000

===

Activity Number = 1020-10
Activity Description = MAINTENANCE OF TRAFFIC 1
Activity's Duration = 11
Activity's Type = ACT
Activity's Unit Measure = LS
Activity's Quantity = 1
Responsible Party = MAIN
Activity's Total Float = 1
Activity Cost = 250

- According to the Department of Transportation specifications, the above activity should have a unit measure = DA (daily).

===

Activity Number = 1040
Activity Description = EROSION MAINTENANCE
Activity's Duration = 8
Activity's Type = ACT
Activity's Unit Measure = ACRE
Activity's Quantity = 5
Responsible Party = MAIN
Activity's Total Float = 4
Activity Cost = 5000

==

Activity Number = 1100
Activity Description = CLEARING AND GRUBBING
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = ACRE
Activity's Quantity = 5
Responsible Party = MAIN
Activity's Total Float = 7
Activity Cost = 25000

- Prior to starting the Clearing and Grubbing operations, the Project Engineer should check that all permits, property rights, waivers, archaeological clearances and property easements have been obtained and are in order.

- The average unit price for Clearing and Grubbing is $4854.11/Acre.

- Check the activity cost for the above activity.

==

Activity Number = 1205
Activity Description = REGULAR EXCAVATION
Activity's Duration = 3
Activity's Type = ACT
Activity's Unit Measure = CY
Activity's Quantity = 8000
Responsible Party = MAIN
Activity's Total Float = 1
Activity Cost = 20000

==

Activity Number = 1600
Activity Description = STABILIZATION/SUB-GRADE
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 600
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 800

- The productivity rate of Stabilization/Sub-grade work is typical 500 SY/day but not to exceed 10 days.

- The average unit price for Stabilization/Sub-grade is $1.31/SY .

- Check the duration estimate for the above activity.

- Check the activity cost for the above activity.

===

Activity Number = 2200
Activity Description = BASE CONSTRUCTION
Activity's Duration = 4
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 3000
Responsible Party = MAIN
Activity's Total Float = 3
Activity Cost = 30000

- Before placing base material, the Inspector must make sure the sub-grade is firm and unyielding, has passed bearing test, and meets grade and cross section requirements.

- The productivity rate of Base Construction, when volume is between 10,000 SY and 260,000 SY, follows the equation: Duration = 0.000028 Volume + 9.43.

- Check the duration estimate for the above activity.

===

Activity Number = 3000
Activity Description = PRIMING
Activity's Duration = 2
Activity's Type = ACT
Activity's Unit Measure = GA
Activity's Quantity = 1200
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 1200

- The base must be permitted to cure before the prime coat is applied. The moisture content must not exceed 90% of the optimum moisture at the time of priming.

==

Activity Number = 3270
Activity Description = MILLING EXISTING PAVEMENT
Activity's Duration = 2
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 20000
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 20000

- The above activity does not have the correct description. Each activity should have a unique description and nonstandard descriptions should be avoided.

- The productivity rate for Milling Existing Asphalt Concrete is 8000 SY/day but not to exceed 20 days.

- Check the duration estimate for the above activity.

==

Activity Number = 3500
Activity Description = PAVEMENT
Activity's Duration = 2
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 20000
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 20000

- Asphalt plant operations should never be started until the weather conditions at the lay-down site are suitable for placing the mix. Temperature should not be less than 40 F or more than 120 F. If wind is blowing to the extent that dust, fine sand and debris are being deposited on the tacked surface that is being paved, then operation should be ceased.

- The productivity rate of Pavement work, when volume is less than 65,000 Tons, follows the equation:

$$\text{Duration} = 0.008\ \text{Volume} + 5.$$

- The average unit price for Asphalt Pavement ranges between \$1.81/SY and \$9.30/SY .

- Check the duration estimate for the above activity.

- Check the activity cost for the above activity.

===

Activity Number = 5200
Activity Description = CURB AND GUTTER
Activity's Duration = 4
Activity's Type = ACT
Activity's Unit Measure = LF
Activity's Quantity = 24000
Responsible Party = SUB
Activity's Total Float = 3
Activity Cost = 24000

- The productivity rate of Curb and Gutter work should range from 400 to 800 LF/day.

- The average unit price for Curb and Gutter ranges between $6.11/LF and $26.10/LF .

- Subcontractors performing 10% or more of the total contract work are considered major subcontractors, and should participate in the contractor's development plan.

- Check the duration estimate for the above activity.

- Check the activity cost for the above activity.

===

Activity Number = 5205
Activity Description = SIDEWALK
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = LF
Activity's Quantity = 500
Responsible Party = SUB
Activity's Total Float = 3
Activity Cost = 10000

- According to the Department of Transportation specifications, the above activity should have a unit measure = SY.

- Each activity must have a consistent unit measure for the purpose of evaluating and analyzing activities durations and costs.

- The average unit price for Sidewalk ranges between $11.75/SY and $19.86/SY.

- Check the activity cost for the above activity.

===

Activity Number = 5700
Activity Description = SEEDING
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 24200
Responsible Party = SUB
Activity's Total Float = 7
Activity Cost = 1500

- The productivity rate of Seeding work should be 23,500 Sy/day, but not to exceed 5 days.
- The average unit price for Seeding is $0.05/SY .
- Check the duration estimate for the above activity.
- Check the activity cost for the above activity.

==

Activity Number = 5750
Activity Description = SODDING
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 600
Responsible Party = SUB
Activity's Total Float = 7
Activity Cost = 1200

- The productivity rate of Sodding work should be 500 SY/day, but not to exceed 10 days.
- The average unit price for Sodding ranges between $1.04/SY and $1.99/SY.
- Check the duration estimate for the above activity.
- Check the activity cost for the above activity.

==

Activity Number = 7060
Activity Description = REFLECTIVE PAVEMENT MARKERS
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = EA
Activity's Quantity = 500
Responsible Party = SUB
Activity's Total Float = 0
Activity Cost = 2000

- The average unit price for Installing Reflective Pavement Markers ranges between $1.04/SY and $1.99/SY .

- Check the activity cost for the above activity.

==

Activity Number = 7100
Activity Description = STRIPPING
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = LF
Activity's Quantity = 6000
Responsible Party = SUB
Activity's Total Float = 0
Activity Cost = 20000

==

Activity Number = 7360
Activity Description = UTILITY RELOCATION
Activity's Duration = 5
Activity's Type = ACT
Activity's Unit Measure = LS
Activity's Quantity = 1
Responsible Party = SUB
Activity's Total Float = 0
Activity Cost = 10000

==

Activity Number = 9999
Activity Description = END OF JOB
Activity's Duration = 0
Activity's Type = ACT
Activity's Unit Measure = NONE
Activity's Quantity = 0
Responsible Party = NONE
Activity's Total Float = 0
Activity Cost = 0

==

Activity Number = 99999
Activity Description = PROJECT DURATION
Activity's Duration = 13
Activity's Type = HAM
Activity's Unit Measure = NONE
Activity's Quantity = 0

Responsible Party = NONE
Activity's Total Float = 0
Activity Cost = 0

===

HighWay Construction Schedule Analysis (HWCSAS) Report 3

Activity Number = 1000
Successor Activity = 1010
Activities Link Type = A
Activity Lead Time = 0

===

===

Activity Number = 1010
Successor Activity = 1020-10
Activities Link Type = S
Activity Lead Time = 1

===

===

Activity Number = 1010
Successor Activity = 1040
Activities Link Type = S
Activity Lead Time = 1

===

===

Activity Number = 1010
Successor Activity = 1100
Activities Link Type = S
Activity Lead Time = 1

===

===

Activity Number = 1010
Successor Activity = 1205
Activities Link Type = S
Activity Lead Time = 1

==

==

Activity Number = 1205
Successor Activity = 1600
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 7360
Successor Activity = 1600
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 5200
Successor Activity = 2200
Activities Link Type = S
Activity Lead Time = 2

==

==

Activity Number = 2200
Successor Activity = 3000
Activities Link Type = S
Activity Lead Time = 2

==

==

Activity Number = 3270
Successor Activity = 3000
Activities Link Type = A
Activity Lead Time = 0

Activity Number = 1600
Successor Activity = 3270
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 3000
Successor Activity = 3500
Activities Link Type = S
Activity Lead Time = 1

==

==

Activity Number = 5205
Successor Activity = 5200
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 1100
Successor Activity = 5700
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 5700
Successor Activity = 5750
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 7100
Successor Activity = 7060
Activities Link Type = A
Activity Lead Time = 0

==

Activity Number = 3500
Successor Activity = 7100
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 5750
Successor Activity = 7100
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 1000
Successor Activity = 7360
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 7060
Successor Activity = 9999
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 1020-10
Successor Activity = 9999
Activities Link Type = A
Activity Lead Time = 0

==

==

Activity Number = 1040
Successor Activity = 9999
Activities Link Type = A
Activity Lead Time = 0

```
Activity Number = 1000
Successor Activity = 99999
Activities Link Type = A
Activity Lead Time = 0

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Case Study 2

Time Scale Report by Activity Number

```
PROJECT: Florida Highway Maintenance 2       START DATE: 07MAR94
SPONSOR: Civil Engineering Department       FINISH DATE: 17MAR94
>==>Critical >-->Non-Critical >..>Free Float >++>Completed *Milestone
----------------------------------------------------------------------
Activity                           1994 MAR
Number                                  07  08  09  10  11  14  15  16  17
----------------------------------------------------------------------
1000        START                       *   .   .   .   .   .   .   .   .
1010        MOBILIZATION                >============>  .   .   .   .   .
1020-10     MAINTENANCE OF TRAFFIC      |   >----------------------------->...
3000        PRIMING                     |   .   .   >========>  .   .   .
3270        MILLING EXISTING PAVMNT     |   >========>  .   .   .   .   .
3500        PAVEMENT                    |   .   .   .   .   >========>  .
7060        REFLECTIVE PAVEMENT MAR     |   .   .   .   .   .   .   .   >===
7100        STRIPPING                   |   .   .   .   .   .   .   >===>
9999        END OF JOB                  |   .   .   .   .   .   .   .   .
99999       PROJECT DURATION           >]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]]
```

Time Scale Report by Activity Number--Continued

```
PROJECT: Florida Highway Maint. Project   START DATE: 07MAR94
SPONSOR: Civil Engineering Department    FINISH DATE: 17MAR94
>==>Critical >-->Non-Critical >..>Free Float >++>Completed *Milestone
---------------------------------------------------------------------
Activity                     1994 MAR
Number                            18  21
---------------------------------------------------------------------
1000        START                 .   .
1010        MOBILIZATION          .   .
1020-10     MAINTENANCE OF TRAFFIC >  .
3000        PRIMING               .   .
3270        MILLING EXISTING PAVMNT.  .
3500        PAVEMENT              .   .
7060        REFLECTIVE PAVEMENT MAR>  .
7100        STRIPPING             .   .
9999        END OF JOB            *   .
99999       PROJECT DURATION      >   .
```

Network Report by Activity Number

PROJECT: Florida Highway Maint. Project START DATE: 07MAR94
SPONSOR: Civil Engineering Department FINISH DATE: 17MAR94

PREDECESSOR NO. AND DESCRIPTION / ACTIVITY NO. AND DESCRIPTION / SUCCESSOR NO. AND DESCRIPTION		RE TYPE	LEAD TIME	DUR	-EARLY START	DATES- FINISH	TOTAL FLOAT
1000	START			0	07MAR94	04MAR94	0
1010	MOBILIZATION		0		07MAR94		0
99999	PROJECT DURATION		0		07MAR94		0
1000	START		0			04MAR94	0
1010	MOBILIZATION			3	07MAR94	09MAR94	0
1020-10	MAINTENANCE OF TRAFFIC 1	S	1		08MAR94		1
3270	MILLING EXISTING PAVEMNT	S	1		08MAR94		0
1010	MOBILIZATION	S	1		07MAR94		0
1020-10	MAINTENANCE OF TRAFFIC 1			7	08MAR94	16MAR94	1
9999	END OF JOB		0		18MAR94		0
3270	MILLING EXISTING PAVEMENT		0			09MAR94	0
3000	PRIMING			2	10MAR94	11MAR94	0
3500	PAVEMENT		0		14MAR94		0
1010	MOBILIZATION	S	1		07MAR94		0
3270	MILLING EXISTING PAVEMENT			2	08MAR94	09MAR94	0
3000	PRIMING		0		10MAR94		0
3000	PRIMING		0			11MAR94	0
3500	PAVEMENT			2	14MAR94	15MAR94	0
7100	STRIPPING		0		16MAR94		0
7100	STRIPPING		0			16MAR94	0
7060	REFLECTIVE PAVEMENT MARKER			1	17MAR94	17MAR94	0
9999	END OF JOB		0		18MAR94		0
3500	PAVEMENT		0			15MAR94	0
7100	STRIPPING			1	16MAR94	16MAR94	0
7060	REFLECTIVE PAVEMENT MARK		0		17MAR94		0
1020-10	MAINTENANCE OF TRAFFIC 1		0			16MAR94	1
7060	REFLECTIVE PAVEMENT MARK		0			17MAR94	0
9999	END OF JOB			0	18MAR94	17MAR94	0
1000	START		0			04MAR94	0
99999	PROJECT DURATION			9	07MAR94	17MAR94	0

Results

Highway Construction Schedule Analysis System (HWCSAS)

FDOT Highway Construction Scheduling Regulations

1- Within 21 calendar days after the contract had been awarded or at the preconstruction conference, which ever is earlier, the FDOT requires from the contractor to submit a work progress schedule for the project. The schedule shall show the various activities of work in sufficient detail to demonstrate that the contractor has a reasonable plan to complete the project on time.

2- Sufficient association shall be conducted and information provided to the FDOT to indicate coordination of activities with utility owners having facilities within the project limits. The schedule shall conform to the utility adjustment schedules included in the contract documents unless changes are mutually agreed upon by the utility company, the contractor and the FDOT.

3- The FDOT District Scheduling Engineer, with the involvement of the Resident Engineer, reviews the schedule, and if it meets the contract requirements submits it to the District Construction Engineer for approval.

4- If the schedule submitted is determined to be inadequate by the FDOT Engineer, it will be returned to the contractor for correction. The contractor will have fifteen calendar days from the date of transmittal to submit a correct schedule.

5- The FDOT establishes contract time in calendar for each project based on the type and volume of the work to be performed. In setting the time, the FDOT considers weekends and holidays. Also, the anticipated affect of utility adjustments or relocations on project progress is considered. Under the calendar day concept, everyday that comes along is a chargeable day (unless contract time has been suspended.)

6- Federal, State and Local environmental permits must be obtained before any work can proceed.

7- External constraints should be considered, including site access, work of other contractors,

local climate and environmental conditions, working schedules of local suppliers, contract milestones, etc.

8- If the construction work requires narrowing the existing road or highway with concrete barricades, the length of the narrowed road or highway must not exceed the specified limit in length by the contract. If the construction work involves more than the specified limit in length, the work must be divided in sections and scheduled in different times.

9- The contractor shall always conduct the work in such manner and sequence to insure the least practicable interference with traffic.

HighWay Construction Schedule Analysis (HWCSAS) Report 1

Project Title = Florida Highway Maint. Project
Project Owner = Civil Engineering Department
Data Date = 2/7/94
Start Date = 3/7/94
Planned Finish Date = 3/17/94
Contract Must Finish Date = 4/7/94
Working Days/Week = 5
Total No. Of Critical Activities = 9
Total Number Of Activities = 10
Total Contract Amount = 46450

==

- The critical path usually consists of relatively few activities (less than 20%). A high ratio of (critical/total) activities might indicate that the contractor did not schedule the project adequately or activities' durations might been overstated for the purpose of eliminating float.

HighWay Construction Schedule Analysis System Report 2

Activity Number = 1000
Activity Description = START
Activity's Duration = 0
Activity's Type = ACT
Activity's Unit Measure = NONE
Activity's Quantity = 0
Responsible Party = NONE
Activity's Total Float = 0
Activity Cost = 0

Activity Number = 1010
Activity Description = MOBILIZATION
Activity's Duration = 3
Activity's Type = ACT
Activity's Unit Measure = LS
Activity's Quantity = 1
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 3000

===

Activity Number = 1020-10
Activity Description = MAINTENANCE OF TRAFFIC 1
Activity's Duration = 7
Activity's Type = ACT
Activity's Unit Measure = DA
Activity's Quantity = 1
Responsible Party = MAIN
Activity's Total Float = 1
Activity Cost = 250

===

Activity Number = 3000
Activity Description = PRIMING
Activity's Duration = 2
Activity's Type = ACT
Activity's Unit Measure = GA
Activity's Quantity = 1000
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 1000

- The base must be permitted to cure before the prime coat is applied. The moisture content must not exceed 90% of the optimum moisture at the time of priming.

===

Activity Number = 3270
Activity Description = MILLING EXISTING PAVEMENT CONCRETE
Activity's Duration = 2
Activity's Type = ACT

Activity's Unit Measure = SY
Activity's Quantity = 18000
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 20000

- The above activity does not have the correct description. Each activity should have a unique description and nonstandard descriptions should be avoided.

- The productivity rate for Milling Existing Asphalt Concrete is 8000 SY/day but not to exceed 20 days.

- Check the duration estimate for the above activity.

==

Activity Number = 3500
Activity Description = PAVEMENT
Activity's Duration = 2
Activity's Type = ACT
Activity's Unit Measure = SY
Activity's Quantity = 18000
Responsible Party = MAIN
Activity's Total Float = 0
Activity Cost = 18000

- Asphalt plant operations should never be started until the weather conditions at the lay-down site are suitable for placing the mix. Temperature should not be less than 40 F or more than 120 F. If wind is blowing to the extent that dust, fine sand and debris are being deposited on the tacked surface that is being paved, then operation should be ceased.

- The productivity rate of Pavement work, when volume is less than 65,000 Tons, follows the equation:
  Duration = 0.008 Volume + 5.

- The average unit price for Asphalt Pavement ranges between $1.81/SY and $9.30/SY.

- Check the duration estimate for the above activity.

- Check the activity cost for the above activity.

Activity Number = 7060
Activity Description = REFLECTIVE PAVEMENT MARKERS
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = EA
Activity's Quantity = 300
Responsible Party = SUB
Activity's Total Float = 0
Activity Cost = 1200

- The average unit price for Installing Reflective Pavement Markers ranges between $1.04/SY and $1.99/SY.

- Check the activity cost for the above activity.

==

Activity Number = 7100
Activity Description = STRIPPING
Activity's Duration = 1
Activity's Type = ACT
Activity's Unit Measure = LF
Activity's Quantity = 10000
Responsible Party = SUB
Activity's Total Float = 0
Activity Cost = 3000

==

Activity Number = 9999
Activity Description = END OF JOB
Activity's Duration = 0
Activity's Type = ACT
Activity's Unit Measure = NONE
Activity's Quantity = 0
Responsible Party = NONE
Activity's Total Float = 0
Activity Cost = 0

==

Activity Number = 99999
Activity Description = PROJECT DURATION
Activity's Duration = 9
Activity's Type = HAM
Activity's Unit Measure = NONE
Activity's Quantity = 0
Responsible Party = NONE
Activity's Total Float = 0
Activity Cost = 0

===

HighWay Construction Schedule Analysis (HWCSAS) Report 3

Activity Number = 1000
Successor Activity = 1010
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 1010
Successor Activity = 1020-10
Activities Link Type = S
Activity Lead Time = 1

===

Activity Number = 3270
Successor Activity = 3000
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 1010
Successor Activity = 3270
Activities Link Type = S
Activity Lead Time = 1

===

Activity Number = 3000
Successor Activity = 3500
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 7100
Successor Activity = 7060
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 3500
Successor Activity = 7100
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 1020-10
Successor Activity = 9999
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 7060
Successor Activity = 9999
Activities Link Type = A
Activity Lead Time = 0

===

Activity Number = 1000
Successor Activity = 99999
Activities Link Type = A
Activity Lead Time = 0

===

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